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MAR 14 2018

IN REPLY
REFER TO: DTIC-R (FOIA 2018-62)

Mr. Cory Newman
MuckRock News
DEPT MR 50429
411A Highland Ave
Somerville, MA 02144-2516

Dear Mr. Newman:

This is in response to your letter dated March 11, 2018, received in this office March 12, 2018, requesting information under the Freedom of Information Act (FOIA) (enclosure 1). Under Department of Defense rules implementing the FOIA, published at 32 CFR 286, your request was categorized as "other."

Document AD0604915, entitled "Remarks on the design, conduct, and analysis of large air exercises" is approved for public release. We are undergoing a system conversion which is creating a delay in our ability to reproduce older documents. There is no projected completion date for the conversion process. Once the process is complete, document AD0604915 will be forwarded to you.

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Sincerely,

Michael Hamilton
FOIA Program Manager

Enclosure

Crawford, Patricia A CIV DTIC RM (US)

From: 50433-86499106@requests.muckrock.com
Sent: Sunday, March 11, 2018 2:28 PM
To: DTIC Ft Belvoir RM Mailbox FOIA
Subject: [Non-DoD Source] Freedom of Information Request: copy of document titled "Remarks on the design, conduct, and analysis of large air exercises"

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Defense Technical Information Center
FOIA Office
8725 John J Kingman Road
Fort Belvoir, VA 22060-6218

March 11, 2018

To Whom It May Concern:

This is a request under the Freedom of Information Act (FOIA) 5 USC 552. I hereby request the following records: PDF copy of document titled "Remarks on the design, conduct, and analysis of large air exercises" Dated May 16, 1955.

Accession Number AD0604915

The requested documents will be made available to the general public, and this request is not being made for commercial purposes. This document is 22 pages long and therefore should be free under applicable FOIA regulations.

In the event that there are fees, I would be grateful if you would inform me of the total charges in advance of fulfilling my request. I would prefer the request filled electronically, by e-mail attachment if available or CD-ROM if not. Please provide me with a FOIA control number so I can track this request.

Thank you in advance for your anticipated cooperation in this matter. I look forward to receiving your response to this request within 20 business days, as the statute requires.

Sincerely,

Cory Newman

Filed via MuckRock.com
E-mail (Preferred): 50433-86499106@requests.muckrock.com

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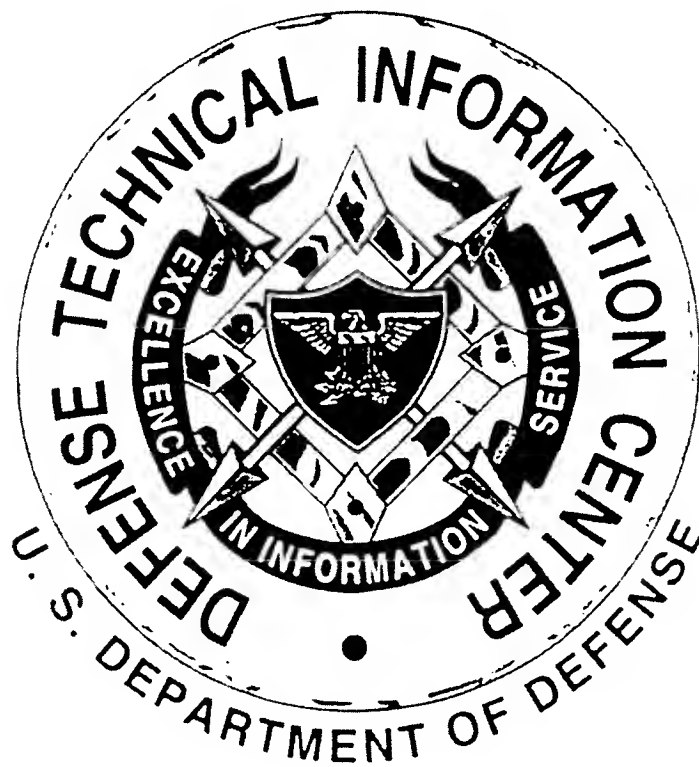
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REMARKS ON THE DESIGN, CONDUCT, AND ANALYSIS
OF LARGE AIR EXERCISES

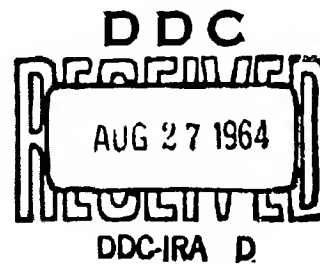
N. C. Peterson

P-700 PH

16 May 1955

Presented to the
Tenth Operations Analysis Technical Conference
Eglin Air Force Base, Florida
May 10-11, 1955

Approved for OTS release



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The following is the text of a talk presented to the Tenth Operations Analysis Technical Conference, which occurred at Eglin Air Force Base, Florida, on 10 and 11 May 1955. This text is being published at the invitation of the Operations Analysis Office, Headquarters, USAF.

REMARKS ON THE DESIGN, CONDUCT, AND ANALYSIS OF LARGE AIR EXERCISES

N. C. Peterson

I am a bit reluctant to stand before this group of practiced and recognized professionals in the arts of analysis and try to say something new and interesting about the conduct and study of Air Force exercises. I expect that every point I hope to make is known by one person or another in this group. Let's then approach these remarks as an attempt to systematize some of the things many of us either already know, or would soon realize if the appropriate circumstances should arise.

These remarks are not intended to be critical of analysts' past and present practices; rather, I propose to look at the practices we would all like to follow.

We are to consider large Air Force exercises. Our point of view will be that of an analyst. My thesis contains the following chain of argument:

- The attainment of an appropriately precise narrative and numerical description of what happened in an exercise--to the offense, to the defense, to the targets, in the data networks and in the several headquarters; and the environment in which these things happened--is an essential prerequisite to any correct recognition and understanding of what the exercise has to teach.
- Many of the lessons taught by the exercise can be discovered and documented only by study of the description.
- The preparation of the description demands the collection of certain kinds of information from all participating units; analysis of the description may require that further data be in hand.
- The design of the exercise missions to provide the information which

is sought, the engineering of an organization to manage the exercise, the naming of the items of information which have to be collected, the selection of sources for their collection, the preparation and distribution of suitable data forms, and the selection and training of recorders demand that a considerable amount of staff and analysis work be done during an extended period preceding the running of the exercise itself. The amount of analytical effort required represents, say, the full-time work of several good men for several months before the exercise. If this important work is ineffectively done, the exercise will be inefficient, for the added cost of this work is trivial in comparison with the aggregate cost of the exercise, and it can make possible the acquisition of tremendously more information than will otherwise be possible. In current Air Force practice, I believe this work is usually incompletely done. In order to improve this situation, the analysts should first insure their grasp of the work needed and then endeavor to persuade the commands that it would be much to their advantage to provide for its accomplishment.

- Every large exercise requires temporary organizational revisions in the command and communications structures of the forces in order to create the exercise headquarters. These headquarters never function as smoothly or well as could be desired; no organization functions well in the first hours of its operation. To help insure the smooth, efficient, and effective operation of the communications and command structures set up for an exercise, it would, most probably, be worthwhile to conduct an appropriate command post exercise, without movement of units, before the actual operating exercise is attempted.

These are some of the main points of my remarks; they show the general direction to be followed. It will be apparent as we proceed that the remarks

emphasize exercises whose purpose is the study of tactics for offense forces. This selection permits statements to be made in more definite form than would be possible if the attempt were made to discuss exercises in general.

The word "exercise" is loosely used in the Air Force to denote a rather broad band of activities; it will be worthwhile to pause here a moment to look at this band, because the kinds of information that can be drawn from a particular exercise, and the difficulty or ease of doing so, depend upon where in the band of possible exercises the particular one lies. An easy way to characterize an exercise is to observe the extent of its departure from the characteristics of an ideal test. In an ideal test the device or tactic under scrutiny is presumed to be in existence in practiced, workable form; the test is conducted under controlled conditions (that is, observations are made under specific, predetermined conditions or situations); and the data are collected by expert recorders and perhaps also by special instrumentation tailored to the test. The analysts provide most of the direction to test operations.

An exercise, on the other hand, is primarily a military show. The emphasis is on the development of tactics, techniques, or equipment, on the maintenance of proficiency in their use, or on the discovery of organizational or material requirements. The collection of data and the conduct of analyses are essential parts of both tests and exercises, but for exercises these activities are much more difficult and require more detailed and extended preparation. The difficulties arise from several causes, which represent departures, of greater or lesser magnitude, from the properties of an ideal test, namely: not all of the tactics or equipments under scrutiny are in hand in practiced, workable form; the conditions of the test are not closely controlled (indeed, one of the goals of an exercise may be to investigate how well can designed conditions be achieved by an operating force with incomplete specific prior practice); the data opera-

tions are frequently so numerous and far-flung that data collection everywhere by expert recorders is impossible (and hence resort must be taken to recruited recorders whose performance will reflect the temporary nature of their assignments); much special instrumentation, otherwise desirable, is inconvenient or infeasible; and the senior exercise management is perhaps less interested in adequate documentation than in other facets of the operation. These properties of an exercise place all the more premium on the quality and completeness of the staff and analysis work done before, during, and after the exercise. If this work is inadequately done, much information, potentially available, is lost.

It is unfortunate that in large-scale Air Force operations, staged for the evaluation of force tactics, the level of proficiency and familiarity required--on the part of those designing, those operating, and those recording--to make the operation a test, is rarely achieved. The briefing, the sortie of the force, the execution of the tactic, the observation, and so on are not polished and hence a host of important effects which, in any honest sense, are external to the worth of the tactic itself, either actually or seemingly assert themselves in its execution and influence the success and the reputation which the tactic achieves. Among such effects are: the coordination between individual aircraft in a formation; the coordination between formations; the pilots' ability or luck in finding the right targets, check-points, and let-down points; the force's withdrawal from the exercise area in a manner which may or may not reasonably simulate wartime behavior; the dissemination of the word on the speeds and altitudes to be followed; the reliability of people's memories of new radio call-signs and special procedures, and so on. A further effect which has little to do with proficiency, but which can very much bias the appreciation of a tactic, is the

weather. Weather influences the launching and recovery of aircraft, visibility, contrails, ground-speed, and radar performance.

There are some good reasons why the large operations are not, and perhaps should not be, tests. For one thing, the planners usually have a number of alternative tactics in mind that they want to try and, in point of time and money consumed, it would simply be infeasible to exercise the force sufficiently to polish the tactics before evaluation is attempted. Also, the consolidation of a large force for an operation necessarily involves temporary dislocations of personnel and equipment and may result in a period of reduced readiness to face actual warfare. In theaters overseas, the conduct of a large operation involves diplomatic arrangements to clear an exercise area. Furthermore, many people feel it is good for the Air Force to operate with unfamiliar orders now and then, to create and maintain a useful level of force flexibility.

There is justification for emphasizing the importance of these "external" factors to the success achieved by a tactic. The first thing which must be recognized by operation planners is that if the operation is large, it is going to be something of a first rehearsal. To some extent the force will be like a football team going into a game having studied its plays only on the blackboard. In recognition of this fact, provisions must be made in the exercise design, and later in the conduct of the exercise and its analysis, for the collection and study of information sufficient to enable the influence of the external factors to be described both qualitatively and quantitatively. One will be wholly unable to get down to a study of the tactics themselves, which the force has attempted, unless he has, during the design, conduct, and preliminary analysis, made explicit and adequate provision for the identification of, and at least partial compensation for, all those inevitable effects. This work entails at least

three important considerations: one is special provisions for collection of the essential environmental and performance data; another is the replication, if possible, of mission designs; and the last is the conduct of some analyses in order to understand how to employ the information on the influence of external factors. Far and away the most difficult of these is the arrangement for replication of mission designs. Commanders hate to drag things on. Analysts would do well to emphasize at every possibility that no single test or experiment is ever statistically decisive. They should try to underline to all who use the reports of analyses how very limited is the significance of limited data.

An operation of large forces does not have to be all novelty, however. A great deal can be, and in certain instances is, accomplished by force commanders toward sharpening the performance of their commands. Commanders should be urged to have their aircrews practice the components of force tactics: teach pilots to fly a line abreast beyond visual range (score it by radar); have them practice the precise attainment, in both space and time, of unfamiliar check-points and initial-points; teach them to take off on time and to observe radio discipline; urge offense force wing and squadron commanders to establish close cooperation with the radar stations in the vicinity of their bases, so that frequent, small, almost unofficial sub-exercises can be run and simply scored.

Let's now approach more closely the business of design, conduct, and analysis. Consider first design, and let's agree not to focus principal attention on the statistical aspects of design. We have all studied the statistical design of experiments and we know that there are good designs and bad ones, that an observed quantity is not observed exactly, that data can be sour, that statistical controls should be built into an experiment,

that the quality of our estimates is improved, in general, by repetition of experiments, and so on. We all know most of these things, whether or not we pay attention to what we know. For the present, let's focus our attention on some aspects of management of the design, on some housekeeping chores, and on some notions that have to be kept in mind in order to end up with the hope of a good exercise, one that will have a high yield of information both per hour of unit flying and per hour of analysis effort.

The first questions in design are: What is the exercise for? What is the exercise expected to find out? In vague terms these matters are usually suggested in the quotation of exercise objectives which comes down to the planning group from Headquarters USAF or the lesser headquarters in line. In my own experience with five or six exercises, these objectives have not been at all adequately specified. And when they are not adequately specified, there is opportunity for someone to say, after the exercise and the analysis: Why didn't you people do such and so? Surely all of you here have heard that sort of remark, and also: We wanted the distribution of the distances of early warning, not the times; now couldn't you just glance back over your sheets (and there go another three weeks down the rat-hole). I believe it would be a good idea for planners to prepare, for approval by the chief, a memorandum of interpretation, when an exercise objective is received, which interpretation would state exactly what the planners will endeavor to draw from the exercise. It would conclude with a remark that further information will be unobtainable since the flying schedule and the data forms will be simplified to the utmost, compatible with the objectives in the interpretation. In addition to the exercise objectives, planners should understand what the current operational prejudices are. They should recognize that exercise findings which deal with

controversial matters, in particular with matters upon which important people have adopted a position, require vastly more substantiation than non-controversial findings. You only have to prove something once to the chief if he already believes it, but he won't doubt himself until you prove it several times if it conflicts with his judgment.

Having the objectives and the prejudices in mind, the planners should "dry-lab" the analysis required to produce the information sought. Analytical experience is invaluable in this work. For those who don't remember their chemistry courses, "dry lab" means to do chemistry experiments in the library instead of the laboratory--to get precipitates from a textbook of compounds instead of at the bottom of a test tube. By "dry-labbing" the analysis, I mean here that one designs a calculation scheme, or a set of them, that can produce all of the information sought in the exercise, and from the scheme infers what input information has to be collected in the exercise in order to carry out the calculations in earnest. The "dry-labbing" has to be done in sufficient detail to guarantee that all the kinds of input information which will be required are found. It is a great mistake not to "dry-lab" an exercise long before it is flown.

With knowledge of the data requirements, as generated by the "dry-lab" work, one can begin to think of the kinds of missions that will be required to produce that data in usable amounts, and of the sorts of data-collection forms to be needed. Consider first the mission requirements. It probably happens that in most cases the grand strategy of the mission designs are directed by the chief or his deputy for operations. If, with reference to the "dry-lab" work, the mission schedule is found to be inadequate for underwriting conclusions on the questions posed in the exercise objectives, the planners should petition for revision of the schedule, and show proof that if

the schedule is not revised the analysis is going to degenerate into a salvage operation in which the staff tries to rescue what it can from chaotic information.

During the course of the exercise design, analysts would be wise to hunt for information payoffs, in addition to those primarily sought, which can be had for rather minor increase in the total exercise cost. Generally, an exercise is a tremendously expensive undertaking, and the direct cost of the design and analysis phases is practically negligible in comparison. Thus if an increase in the information payoff can be purchased by only proportional increase in the design and analysis effort, the over-all exercise cost will be negligibly affected.

And by the way, as a point of philosophy in design, I urge that in those exercises concerned with force penetration tactics, equal emphasis be given to investigation of the losses inflicted by area defenses and by local defenses. It is usually not done that way. However, in a somewhat loose sense, those tactics which are to be preferred for survival through area defenses are undesirable for penetrating local defenses, and vice versa. This statement is not to be interpreted strictly. Clearly, simple logic demands that in the study of penetration tactics, all the defenses to be penetrated must be considered before some particular mode of operation can be shown to be preferable. And, incidentally, if we are to be honest, we can consider only those local defense penetration tactics which will put the offense in position to launch weapons.

It may be appropriate at this point to say a few words about the design of missions or tactics. All of us, I think, enjoy doing the things we can do-- we like to exercise our capabilities. There is tendency to throw into force tactics the equipment on hand with insufficient study of whether that equipment contributes positively to the success of the tactic: "Take those jammers out

and jam--lay a big river of chaff across in this direction so the defense won't know what's going on--Send in everything else we've got a half-hour ahead of the bombers and run their fighters out of gas." Some tactics with no more foundation than these have been taken quite seriously at times. It isn't necessary to emphasize to this audience that such planning does not necessarily guarantee efficient utilization of one's equipment and capabilities. The design of tactics should be based on a thorough study of the opposition--and I think these remarks apply as well to the design of defense tactics as to offense tactics. In the instance of offense tactics, the planners should consider in detail the essential attributes of a defense system and its components, and should study, then, their own capabilities to find out what uses of which capabilities can interfere in specific ways with the performance of the defense, and thus make positive contribution to the success of the tactic. The combing-over of one's capabilities to find out what he really wants to do can be done systematically, and will be helpful in both the perfection of present plans and the generation of legitimate requirements for future equipment.

Assume now that the mission or flying schedule is approaching final form. Before the planners admit that they are as little dissatisfied with it as they can honestly expect, the schedule should be searchingly examined again by the "dry-lab" technique. Also, the schedule ought to be padded a bit to provide some flying that can, grudgingly, be cancelled because of weather or other causes, without making the exercise data hopelessly incomplete.

The next step in the design is the preparation of the operations orders, including the data collection forms. Thousands of matters have to be accounted for in the orders; some of these are particularly important to the smooth conduct and analysis of the exercise, and insuring their presence in the orders is

worth special effort:

First, a central, over-all command headquarters with full authority is extremely desirable. This headquarters should be responsible for all forces involved to the extent it is feasible to arrange this responsibility. This headquarters should be responsible for both making and disseminating to all participating forces all decisions in regard to any facet of the exercise. It would be most wise to train this headquarters by a command post exercise some time before the operational exercise. Otherwise this somewhat ad hoc group is not likely to function as well as would be desirable.

Next, the orders should require an exercise critique to be held within a few days following the end of flying. The critique must be attended by the exercise commander and his staff and well-informed representatives of all participating units and organizations. The critique should direct its discussions toward the performance of the command and communications structure set up for the exercise and the exercise environment, and should specifically avoid trying to anticipate the results of the exercise analysis. The critique proceedings should be private, informal, sincere, and off the record, with only summary remarks officially recorded. In this way people will be more free in their airing of congratulations and complaints. The critique must have a strong chairman, and he should make it his business to see that people do not use the forum of the critique as a sounding board from which to advance preconceived notions. Those who are to analyze the exercise can collect much valuable information in a critique, for it involves people from all the spheres and levels of activity involved, and all the points of view.

Next, the orders should help provide motivation for the complete execution of all the data collection forms, and detail the machinery for the collection of all the data records to some single place.

When the orders are all prepared, the analysts should procure a complete deck of them and study them in detail for consistency. All courses, briefed check-points, and targets, with the associated times, should be plotted for guidance during the exercise touring, and for later use during the analysis.

Consider now the data collection forms. From earlier work the planners know all the data items that have to be collected. It is necessary to find at least one, and preferably three or four sources from which each item can be obtained. Redundancy of the data is desirable because the capability of people who are filling out forms for becoming inactive or inaccurate is almost beyond description or belief. You people are all familiar with this human characteristic. When an observation is recorded independently by several sources, sour observations can frequently be spotted. Also if there are multiple data sources, chances are that not all of them will be inactive simultaneously.

Data must be collected from the sources on prepared forms. The subject of data forms is worth a full-dress study course in its own right. A few remarks on the design and use of forms are in order here:

First, the execution of data forms takes time, and if this time is taken by people who are actual links in the system under study, then the system is disturbed. Consequently it is worthwhile to have data collected by special recorders who are not themselves linked into the system. It is infeasible to have special recorders collect all data, of course--only the pilot of a fighter can observe his airplane throughout its flight. Special data recorders are usually much more reliable than recorders who are in the system. Pilot reports are particularly unreliable and should never be taken as primary data unless they are otherwise corroborated. The usefulness of pilot reports probably would be increased if, in some way, pilots could be assured, truthfully, that

they would be immune from retribution should they frankly record their actual actions, specifically including their mistakes. I am convinced that much of the unreliability of pilot reports stems from their fear of looking bad on their records, and fear of being reprimanded or otherwise penalized for mistakes. Pilots need both protection from this sort of thing, and motivation to do good flying and reporting. It should be impressed on pilots that incorrect mission reports can lead the command staff into an improper appreciation of the relative effectiveness or desirability of alternative tactics, and thus may lead to a preference for inferior tactics. The inferior tactics could, in combat, force the unnecessary loss of pilot lives or result in other disaster.

Next, controllers should never be their own recorders, since they are very busy, usually, and also have a universal tendency to assign their failures to quirks of their equipment. All analysts know that "target fade" is meaningless in a controller's logbook.

Next, one should try hard to obtain from routine forms used in regular operations most of the data to be required. Special new forms always add to the already considerable burden of paper flowing through the force, they are not readily understood, and frequently meet hostility.

If new forms must be used, they must be carefully and cleverly worked out in order to be easy to understand, difficult to misunderstand, easy and fast to fill out, and easy to read by those who will use the information. The forms should, to the maximum possible extent, be composed either of questions with given multiple-choice answers, for which the correct answer can be indicated by a check-mark, or of data entries which can be given by writing a number in a box. Avoid asking a data collector to write a sentence. Never tell him to "cross out those answers which do not apply" for this instruction is invariably

confused. Never state questions in the negative. Never ask a recorder to make a calculation. Avoid having a recorder draw diagrams; if diagrams are essential, provide printed coordinate grids and be particularly careful that the recorders are properly instructed and exercised.

Finally, a data recorder has to be motivated to do his work properly. Motivation goes beyond either instruction or command. The recorders must be shown how to fill in the forms, what they are used for (in broad terms), be made to feel that the time he spends on the forms is well invested, and he must be given cause to want to fill in the forms properly. He must believe that every data entry on the forms is important. Accomplishing these things is a difficult but essential part of successful force exercising. The only way I know of whereby recorders can be adequately motivated is through personal contact. It is helpful to show recorders the results achieved in previous analyses using their records.

Consider now a few remarks on the behavior of analysts and commanders during the conduct of an exercise.

The commander should have at his elbow a statistician who knows the exercise plan inside and out. This arrangement may require clever selling. The commander will be less interested in the data than will the analyst, but the analyst can nevertheless keep him posted on how the information situation is developing. For one reason or another, missions are always being shuffled around, revised, postponed, and sometimes cancelled during large exercises. An analyst wired-in at the sanctum of command can sometimes provide useful advice to the chief on which missions are the more vital to the completeness of the data scheme. Thus if some flying has to be cancelled, the analyst can attempt to insure that nothing crucial is lost.

The analysts should see everything they can during the exercise, and take

copious notes. The human memory is unreliable. It is a good idea for everyone in the analysis team to write up his notes into memoranda for circulation within the team. In this way, each can profit from the experiences of all in the group.

It is important for each observer and analyst to visit, some time before the exercise, the place or places he will be during the exercise. The purposes are to learn where the place is, how it is laid out, how it operates, to meet and chat with the people and enlist their cooperation, and to arrange for a place to sit or stand where one will be able to keep track of proceedings without disturbing the system. These things must be done beforehand to avoid disturbing the system during the exercise. One should be careful during an exercise not to give away information to those who shouldn't have it. For example, an analyst bursting into a JCI at 5 a.m. with an expectant look in his eye could alert the watch that something is about to happen.

It would be a good thing if the command staff could be persuaded to keep a record of incoming information and to permit a recorder to take notes on staff discussions during an exercise. The records kept are usually only a log of outgoing printed messages; the discussions and verbal commands are lost. A rather complete staff log would be invaluable in the untangling of some of the knots of inconsistent data that may be discovered during an analysis. Analysts are well-advised to snatch up opportunities to interview commanders, staff, and crews when doing so does not disturb the system.

Now the exercise is over but, for the analysts and some of the command staff, the work continues.

It was suggested before that there should be held a critique of the command and communications operations during the exercise.

The analysis staff would be well-advised to ignore the fact that the operations orders, if well written, will have set up machinery for the prompt assembly at some one place of the complete records collected in the exercise by all participating units. The machinery may be helpful, but to insure its action the analysts should disperse to each of the source points and hound them for the records until all have been accounted for. The exercise headquarters should persist long enough to help this work. The analysts should be emotionally prepared for the realization that many of the reports will not have been made out according to the letter, to say nothing of the spirit, of the instructions. Using the records will still be difficult if all the recorders were properly instructed and motivated before the exercise. If they were not so instructed, long hours of frustration are in prospect for the analysts.

We turn now to a few remarks on analysis.

The first big problem of the analysis is to obtain a complete description, in documented numbers and narrative, of what each airplane and group of airplanes, the ground networks, and the command actually did in the exercise, and of what happened to them while doing it. This work must precede any attempt at numerical analysis, discussion, drawing of conclusions, and the like. If the exercise design has been competently done, if the data forms were well engineered, and were distributed, filled-out, and collected, and if there were no major upheavals during the conduct of the exercise, then this task is rather straightforward, though at best it is laborious. On the other hand, should one of the preceding "if" statements not be realized, the job of description may degenerate into the salvage operation mentioned before.

For those who have not experienced what this job of description can entail, let me create an only slightly exaggerated example. Suppose we are dealing with

an exercise designed to evaluate the relative reliability of a set of alternative mission designs for getting an attack force through an area defended by radar-controlled interceptors. The sequence of the main events is: the offense forces approach the defended area, some or all of them are seen by radar, the radar information is evaluated and scramble orders are given, interceptors rise and engage some or all of the offense, the surviving offense aircraft continue to target and turn homeward.

Ideally, the offense could provide, within the accuracy of navigation logbooks, a minute-by-minute record of the location, course, speed, and altitude of each of its aircraft, along with a notation of its base, type, time of take-off, call-sign, side markings, briefed IP's and target, briefed profile, the points where each is attacked, where each sights interceptors, the influence of radio jamming on communication, and the existence or absence of contrails at all points along the route. That would be the offense's picture of things.

The defense network gets a different picture. They see pips on radar scopes, they estimate speeds, altitudes, courses, and positions for the aircraft the pips represent. But the defense isn't positive who are friend and foe, it doesn't know for sure which aircraft are weapon carriers and which are not--maybe none or all are--and they don't know the intended targets. The defense is unsure how many aircraft are present; they worry about being deceived. The defense gives each track it sees a number, and records loads of information on each one, from their viewpoint. Decisions are made, disseminated, and recorded.

Now interceptors leave the ground. An interceptor pilot sees many things, and records some of it. If he sees an offense airplane, he has no sure way of knowing if it is the one he was dispatched and vectored to find. He knows his

position only approximately, and can only guess the heading of the aircraft he sees. Sometimes he can read the markings on his target, sometimes not.

The point of these paragraphs has been to indicate how the offense, the defense ground network, and the defense squadrons each build up stores of more or less inaccurately recorded information about aircraft sent, aircraft detected and tracked, and about aircraft sighted or attacked. But there is no immediate identification of a particular offense sortie with a particular radar track and with a particular interceptor sighting. Obviously this three-sided correlation is essential to the bringing together of all the information recorded on the actions of, and responses to, each offense aircraft. One procedure for approaching this correlation involves the use of plotted overlay maps of aircraft tracks.

Eventually, the narrative and numerical description of the exercise is achieved and the analysis proper can get under way. This task, too, can be rather straightforward if the "dry-lab" work, so helpful in the design stages, was well carried out.

Let me close these remarks by recalling to your memories a few of the arguments advanced in the previous paragraphs:

1. The conclusions from an exercise can be documented only if one knows and can document what happened in the exercise.
2. Only if the influence of the "external factors" can be adequately appreciated and isolated can the conclusions reflect the influence, on the results achieved, of the components of force tactics, or can whole-force tactics be fairly ranked in order of preference. To accomplish this isolation to a useful extent, very

careful and explicit preparations are required.

3. The proper design of an exercise, to be statistically efficient, conclusive, possible to describe and to analyze, and to make possible the collection of all the data and other information sought, requires a large amount of analysis and staff work to be done before the exercise is flown.
4. The command and communications structures set up for an exercise should be given practice beforehand in order to increase the likelihood that these structures will function smoothly.
5. Force commanders can contribute much to the capability of their forces by a continuous program of scored and analyzed small exercises.
6. There are a number of important steps that have to be taken in order to collect useful and adequate data.
Among these are:

The data requirements must be deduced.

The missions must be appropriately designed.

The data sources must be found and the personnel be trained.

Clever collection forms must be engineered, reproduced, distributed, executed, and collected together.

7. In the design of an exercise, analysts should search carefully for information payoffs, beyond those originally required, which can be attained for negligible or minor increase in the over-all exercise cost.

8. In considerations of exercises concerned with force penetration tactics, analysts are urged to give equal emphasis to investigation of the losses inflicted by local defenses and by area defenses.

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MAR 14 2018

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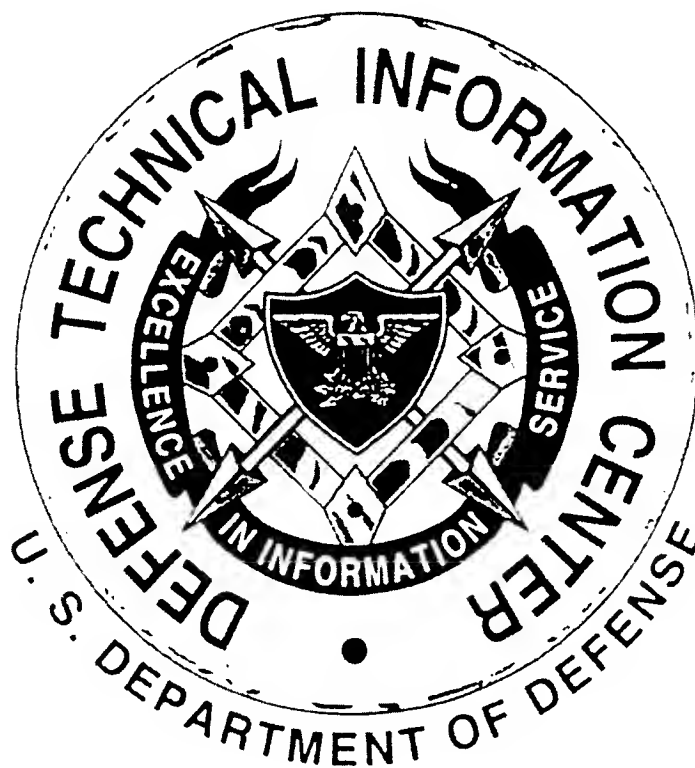
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March 21, 1946

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March 21, 1942 - January 1, 1945

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By: F. E. Terman, Director

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TABLE OF CONTENTS

	Page
I. Introduction.....	1-1
II. Origin of Radio Research Laboratory.....	2-1
III. Origin of a Program	3-1
IV. A Short History of the Laboratory	4-1
V. Technical Accomplishments	5-1
Window.....	5-1
Transmitters.....	5-3
Receivers	5-6
Antennas.....	5-8
Direction Finders.....	5-11
Test Equipment.....	5-12
Anti-jamming	5-13
VI. How the Work was Done	6-1
Conduct of the Research	6-1
Liaison.....	6-2
Transition.....	6-7
Business.....	6-10
Invention Disclosure	6-13
Laboratory Shops.....	6-14
Field Testing.....	6-15
Division 15 and Service Liaison Offices.....	6-15
Demobilization.....	6-16
VII. A Brief Summary of the Operational Use of RCM Equipment in World War II.....	7-1
Introduction	7-1
I. European Theater.....	7-1
II. Pacific Theater.....	7-8
VIII. Evaluation of RCM	8-1

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ii

411-299

LIST OF ILLUSTRATIONS

- Frontespiece The Radio Research Laboratory was quartered in and adjacent to Harvard University's Biology Building
- Figure 1. German "Giant Wurzburg" radar - used for fighter control
- Figure 2. Small "Wurzburg" and Window - The Germans built 4000 of these anti-aircraft fire control sets
- Figure 3. German "Freya" portable early warning radar
- Figure 4. The Radio Research Laboratory's assignment
- Figure 5. This Japanese copy of the SCR-268 was one of the fire control radars jammed by the B-29's
- Figure 6. Early experimental Mandrel-type jammer
- Figure 7. Single Dial Tuning Unit
- Figure 8. View of Florosa Field; hangar and building used by RRL field group
- Figure 9. Test Laboratory; shake table at left; cold chamber at right
- Figure 10. Tuba: 500 megacycle arc at 50 kw power level
- Figure 11. Buildings of the American-British Laboratory
- Figure 12. Prototype PB4Y2: countermeasures antenna blisters under nose
- Figure 13. Early B-17 Ferret planes at Foch Field, Algiers
- Figure 14A.
- Figure 14. AN/ARQ-8 guided missiles jammer installed aboard a destroyer
- Figure 15. 1000-3000 megacycle lighthouse tube local oscillator for AN/APR-5
- Figure 16. Representative Model Allocation List
- Figure 17. Top view of the Carpet I transmitter
- Figure 18. Elephant aboard the U.S.S. Asheville; receiving position
- Figure 19. Growth of the Radio Research Laboratory
- Figure 20. Early British leaflet Window
- Figure 21. How the Window cutter operates
- Figure 22. The L-shaped patch on the PPI at 7 o'clock is Window; planes are visible inside apex of "L"
- Figure 23. A common sight in Germany: Birdsnest beside an autobahn
- Figure 24. Taped all-metal Chaff; RR-4/U
- Figure 24A
- Figure 25. 200 pound, 150 watt airborne magnetron jammer - AN/APT-4
- Figure 26A. Artist's conception of the production Tuba equipment as set up in England
- Figure 26. Exploded view of the AN/APT-9 lighthouse tube oscillator
- Figure 27. 150 watt TDY jammer at the left; one kilowatt Elephant transmitter console at right
- Figure 28. AN/APR-5 microwave intercept receiver. 1000-3000 Mc lighthouse tube oscillator in center
- Figure 29. AN/APA-23 recorder for search receivers
- Figure 30. AN/SPQ-27 microwave spot jamming system installation
- Figure 31. Rotatable directional antenna used with shipborne TDY jammer
- Figure 32. AS-69/APT "Fishhook" rotating polarization anti-Wurzburg radar antenna
- Figure 33. Twin stubs raked backward and fed through "bazooka", give horizontally polarized signal with maximum forward
- Figure 34. TDY-1A 10 Cm, circularly polarized rotatable jamming antenna (cutaway view)

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LIST OF ILLUSTRATIONS (Continued)

- Figure 35. Components of AN/APA-17 rotating reflector direction finder
- Figure 36. Wide-band "Slot" antennas like these can be mounted flush with skin of plane
- Figure 37. The services were actively interested in anti-jamming training
- Figure 38. RRL helped train the Services in the use of new equipments
- Figure 39. Graph of incoming Service project requests
- Figure 40A.
- Figure 40B.
- Figure 40.
- Figure 41. Main drafting room
- Figure 42. AN/APA-24 direction-finder top mounted on a B-24
- Figure 43. View of the RRL Hangar at the Bedford Airport
- Figure 44. RRL technical observer briefing flight crews on countermeasures
- Figure 45. From an Army installation photograph: barrage Carpets in a B-17
- Figure 46. Radar anti-jamming study
- Figure 47. Closeup of circularly polarized microwave jamming antenna (M4902)
- Figure 48. Representative AN/APA-17 scope patterns - low and high frequency
- Figure 49. P525A jamming signal generator - for training use
- Figure 50. Under side of single dial tuning unit, showing variable cam
- Figure 51. A portion of the Machine Shop
- Figure 52. Molding a "blister" in the Wood Shop
- Figure 53. A corner of RRL's Test Laboratory
- Figure 54. Press notices: clippings of articles based on the Laboratory's press release
- Figure 55. Spot jamming installation in a B-17
- Figure 56. RCM installation in a PB4Y-Z search bomber
- Figure 57. DBM spinner mounted above the radar on the foremast of a DE
- Figure 58. Carpet transmitters as they arrived at an installation depot in England
- Figure 59. Laboratory prototype of the TDY transmitter
- Figure 60. Wide-band dipole antenna developed for interim shipboard use
- Figure 61. The AN/APA-24 Direction Finder is provided with a line of interchangeable heads
- Figure 62. The AN/APT-9 lighthouse tube jammer
- Figure 63. Aircrew member ejecting Window bundles from B-17
- Figure 64. Radar coverage map of Japanese Home Islands
- Figure 65. Remains of a Japanese radar on the Aleutian Island of Kiska
- Figure 66. Two types of Rope - a countermeasure widely used against the Japanese
- Figure 67. Showing antenna for RCM installation in Navy carrier-based Fighter plane
- Figure 68. AN/APT-1 200 megacycle jammer - widely used in the Pacific
- Figure 69. Photomultiplier noise tube and modulator

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411-299

LIST OF ILLUSTRATIONS (Continued)

- Figure 70. Gas tube noise modulator - more effective and simpler than its predecessor
- Figure 71. Noise jamming as it appears on a typical radar "A" scope
- Figure 72. Antenna research in progress on the RRL roof
- Figure 73. The Resnatron tube should have important post-war applications
- Figure 74.
- Appendix A

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PREFACE

The Administrative History of the Radio Research Laboratory is intended to be an over all summary of the Laboratory's activities and accomplishments during its three and one-half years of existence. In effect, the History represents a statement to NDRC Div. 15 of the concrete results achieved by an expenditure of nearly \$15,000,000 of public funds for radar countermeasures research and is analogous to the Annual Report of the President of an educational institution. It is also believed that the History will be useful as a guide to future researchers in the field, since it gives a survey of the over all problem of radar countermeasures research in World War II. From the experience of the past war, it should be possible to gain some idea of the problems which may come up again in any future conflict.

This volume, taken with the reports entitled "Summary Technical Report - Part I" (411-302), "Summary Technical Report - Part II" (411-301), and "Document Digest" (411-64c) are to be considered the Contractor's Final Report of Findings in satisfaction of the terms of Contract OEMsr-411.

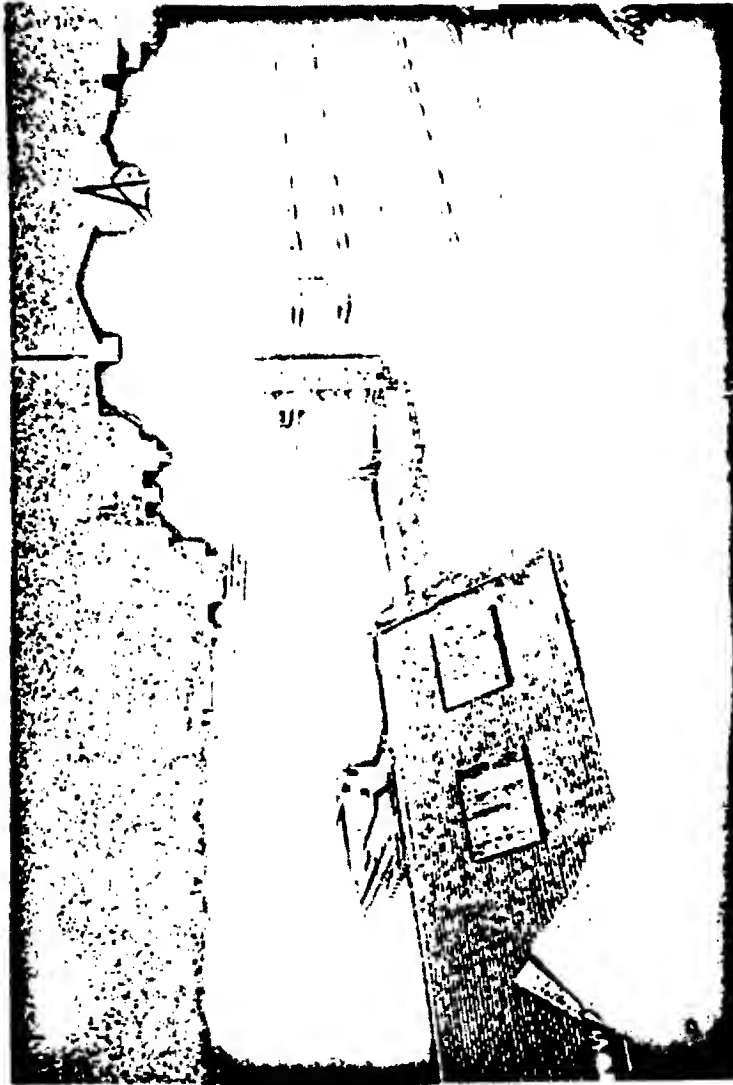
Acknowledgement is due to Oswald G. Villard, Jr. who carried the chief responsibility for compiling this portion of the Contractor's final report.

Frederick Emmons Terman
Director

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The Radio Research Laboratory was quartered in and adjacent to Harvard
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1-1

I. INTRODUCTION

The successful prosecution of the war demands that the enemy be denied the use of any weapons which he may bring to bear against us. This denial should be as complete as possible within the limits of the available manpower; in this way, the challenge of the submarines was answered by patrol planes and destroyers, and the challenge of the buzz bomb was answered by fast fighters and accurate anti-aircraft fire.

America's entry into World War II brought about immediate changes in United States military policy in relation to radar. Prior to Pearl Harbor, the task had been to develop this new technique, and to evaluate its possibilities. After Pearl Harbor, with definite enemies and a definite order of battle in mind, the emphasis shifted to the quantity production of radar developments as required.

Radar countermeasures followed much the same course. Prior to the war, some research work of a long-range character had been carried on in Service laboratories. After Pearl Harbor, it became clear that if the enemy's radar was as useful to him as we expected our own would be useful to us, it would be necessary to put a major effort into developing countermeasures against specific German and Japanese equipments. This feeling was reinforced by the experience of the British, who had already used radio and radar countermeasures successfully in the defense of their homeland, and attached a high and increasing importance to this activity.

In the realization that an expanded research and development program would be required, the services formally requested, late in December, 1941, that the National Defense Research Committee undertake a project in the field of radar countermeasures. This is a report on the laboratory which was created in answer to that request.

Radar countermeasures depend on the fact that radar has certain fundamental weaknesses which, when systematically exploited, can remove a very large percentage of its usefulness. Because a radar set is no more than a special kind of a radio station, it can be located and pin-pointed with the aid of radio direction finders. Because it is constantly sending out strong radio signals, it can be heard at a great distance - in fact, at a much greater distance than the farthest range at which it can detect an object. Moreover, since a radar depends for its operation on the weak echo returned from a distant target, it can be jammed or "blinded" by a relatively low-power transmitter located at or near the target and tuned to the radar's frequency channel. Finally, since radars cannot distinguish the exact nature of relatively small objects such as ships or airplanes, they can be deceived by false "targets" consisting of many strips of tinfoil allowed to fall freely through the air.

These and other weaknesses of radar were fully exploited by the Radio Research Laboratory (RRL) during its three and one-half years of existence. Starting out in March, 1942 with less than 25 employees, it had grown by August, 1944 to its peak strength of some 810 persons. A total of \$15,000,000 was spent on the Laboratory activities - research and model construction. An additional \$710,000 was spent on Division 15's overseas laboratory in England - American British Laboratory of Division 15 (ABL-15), which was administered and staffed through RRL, and at its maximum had over 70 employees. Over 150 equipments developed at RRL were the

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basis of service procurement. Service orders for these developments totalled \$242,000,000, or 570,000 items, of which \$160,000,000 worth (427,000 items) were delivered by October, 1945. The number of items is exclusive of Window, of which some 30,000 tons were produced. Thus every dollar spent on research at RRL resulted in over ten dollars' worth of equipment delivered to the Services.

In addition, the Laboratory built, or had built under sub-contract, some 2,880 items of equipment, worth \$2,680,000, which were turned over to the Services for test and experimental field use without transfer of funds. In cases where urgent operational need existed for equipment which could not be procured in time by the services in any other way, the Laboratory produced or arranged for the production of an additional \$2,805,000 worth of models for which OSRD was reimbursed by a transfer of funds. Of this amount, \$1,910,000 was spent for three 50-kilowatt "Tuba" jammers turned over to the Royal Air Force (RAF) and paid for by the British through Lend-Lease. The remainder, \$895,000, represents the cost of over 460 additional items "crash" produced for the Army and Navy.

Since the Service orders for all countermeasures equipment approached \$300,000,000, it can be seen that in dollar volume, countermeasures represented an activity almost one-tenth that of radar itself; yet the National Defense Research Committee (NDRC) countermeasures program got under way roughly a year and a half later than its radar counterpart.

The task of supplying equipment to blind the enemy radar "eyes", wherever they were encountered, presented RRL with many problems that were unique. In almost no other field of wartime research was the work which was done tied in so closely with tactics - not only our own, but also enemy tactics. Since the preparation of radar countermeasures requires both a knowledge of operational plans and intelligence information about the enemy as well, it is no surprise that the research work had to be carried out with the greatest possible security. In addition, the constantly changing nature of the enemy tactical and technical position, and our relationship to it, made it necessary to supply finished countermeasures equipment to the Armed Forces with a dispatch greater than that needed in the case of any other electronic equipment. This accelerated pace meant that many of the technical decisions had to be made with what would be, in normal practice, insufficient information. The success of the countermeasures program as a whole, however, demonstrates that the enemy was thoroughly out-guessed.

In addition to designing and developing the countermeasures equipments, RRL rendered many other important but less tangible services as well. By serving as a central clearing house for radar countermeasures (RCM) information, RRL helped by keeping all concerned up to date on the latest events. By following the progress of its developments from the time they left the Laboratory to the time they were in operational use, RRL provided a follow-through essential to the success of its share of the program. An important part of this phase of the work was the Laboratory's technical observers and field representatives, of which 74 were sent to the European theater, principally through ABL-15, 17 to the Mediterranean theater, and 23 to the various Pacific theaters.

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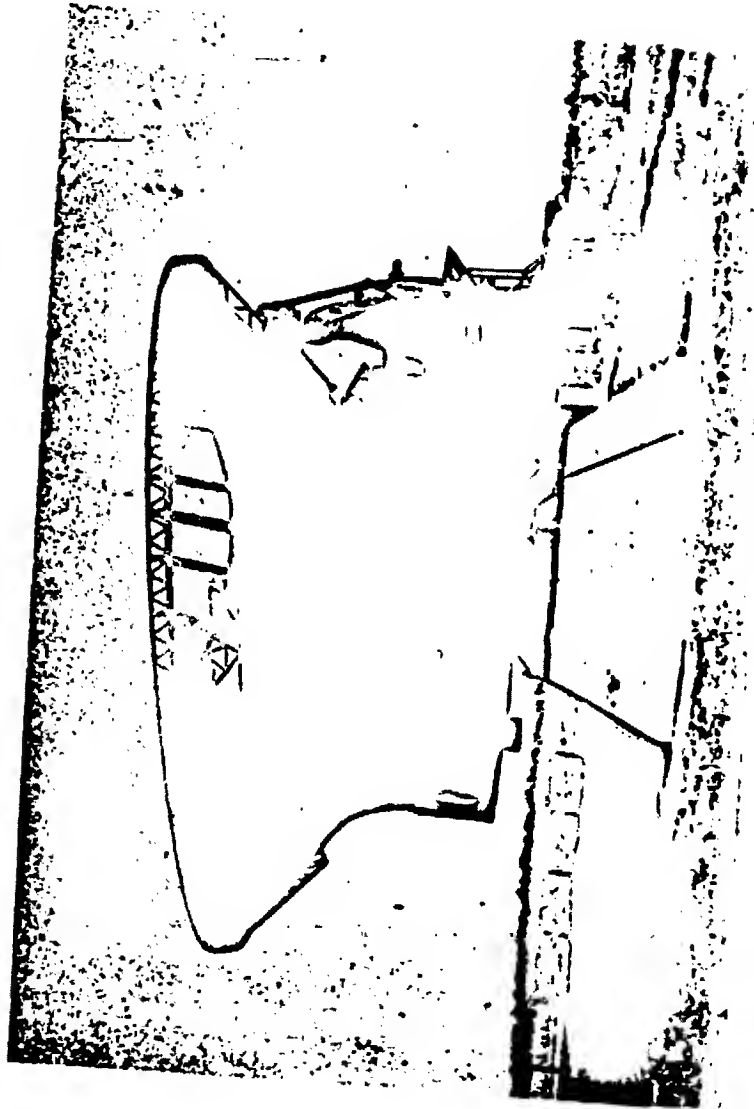


Figure 1. German "Glast Wurfung" radar - used for fighter control

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Figure 2. Small "Wursburg" and Window - The Germans built 4000 of these anti-aircraft fire control sets

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2-1

II. ORIGIN OF RADIO RESEARCH LABORATORY

In late 1941 little knowledge was available in the United States on the state of enemy radar development or on the possibilities of radar countermeasures. It was known that the British were planning countermeasures against German radar, but few details on the enemy equipment were available. It was not known for certain whether or not the Japanese had radar.

Those concerned with the development of new and improved radar equipment had given the possibilities of countermeasures a certain amount of thought. In particular, the Microwave Committee of NDRC had authorized the development of a radar search receiver for the frequency range in which, according to British reports, the German radars were operating.

As a result of a meeting at the Navy Department on December 27 between Navy and NDRC representatives, it was decided that an official request would be sent to NDRC for the establishment of a countermeasures research and development group. This request went forward immediately, and the problem was temporarily assigned to the Radiation Laboratory at the Massachusetts Institute of Technology at Cambridge, Mass. Dr. F. E. Terman, then head of the Electrical Engineering Department at Stanford University, was selected to be Director of the new project. Recruiting of key personnel began at once and some had already been obtained by the time Dr. Terman arrived in Cambridge in February, 1942. Temporary quarters were made available to the new project in the Hood Building at the Radiation Laboratory. Effective March 21, 1942, Harvard University accepted an NDRC contract covering the countermeasures research, and responsibility for the work was transferred from M.I.T. to Harvard. In July, 1942, the Radio Research Laboratory's equipment was moved to Harvard, where the laboratory was set up in a wing of the University's Biology Building.

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III. ORIGIN OF A PROGRAM

The first of many tasks facing the Director of the new project was the matter of securing personnel, since by the time RRL was started, most of the major U. S. wartime research projects were already under way. The Laboratory's first Associate Director, Dr. R. W. Hickman of Harvard University's Cruft Laboratory, provided invaluable assistance in the recruiting work, particularly in view of his connections at Harvard. However black the problem may have looked at first, as time went on more and more sources of manpower were found, since each new arrival seemed to know of one or two friends who might be available. In this way, the number of research associates at the Laboratory increased almost linearly until September, 1943, when it reached some 200 persons - a level which was maintained until the Laboratory's demobilization.

A great contribution to the Laboratory's effort in the early days, was an arrangement with the Columbia Broadcasting System (CBS), whereby a substantial proportion of its television research staff was made available for work on the new project. Some of the members of this group, such as Dr. Peter Goldmark and Mr. John Dyer, divided their time between RRL and CBS's television laboratory in New York, virtually all of which was devoted exclusively to countermeasures research. The work at New York was coordinated by RRL, and for many months was carried on under sub-contracts from RRL.

The securing and organizing of the necessary facilities needed to carry out a research program consumed a large portion of the time of RRL's personnel in the early days. Machine tools, electrical equipment, radio parts, etc., all had to be obtained as rapidly as possible at a time when severe shortages in these items were making themselves felt. Special laboratory test equipment had to be constructed, and provisions had to be made for facilities to test new developments in aircraft - to mention but a few of the items which required attention.

Starting a laboratory and getting it into operation in the shortest possible time, required the establishment of many new procedures, such as methods of handling stock, the control of shop work, etc., which are taken for granted in long-established concerns. Secrecy requirements and increasing war burdens on the administrative departments of the University resulted in development of a virtually autonomous laboratory organization, with its own purchasing, expediting, accounting, and other service functions sufficient for self-sustaining operation. To organize and administer these non-technical functions the University loaned Mr. N. Preston Breed, Assistant to the Treasurer, to serve as Business Manager of the laboratory throughout its existence.

Since the art of radar itself was relatively new and virtually unheard-of to those who had previously been working outside this particular field, it was necessary for each newly acquired Laboratory member to acquire considerable indoctrination. To this end, informal courses and lectures were given, and much help was obtained from a few Radiation Laboratory staff members who had been assigned to help out the new project.

Since RRL's assignment was very indefinite (the contract merely stated that the Laboratory should "work in the field of radar countermeasures") it was necessary to formulate a starting program on the basis of very little prior knowledge. To give some idea of the difficulty of estimating the situation in the early days,

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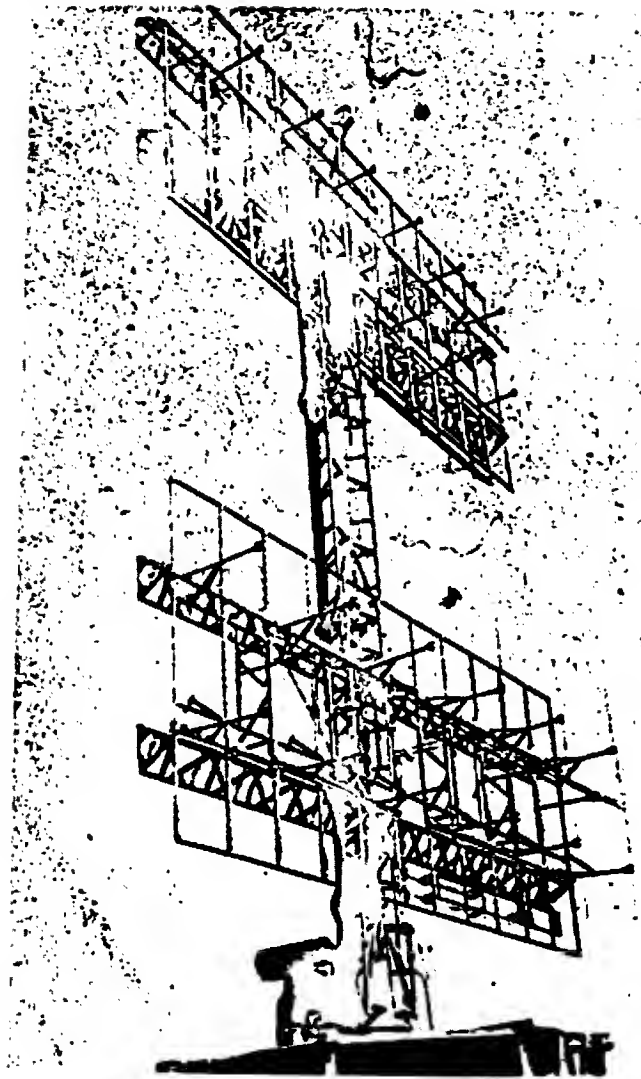


Figure 3. German "Freya" portable early warning radar

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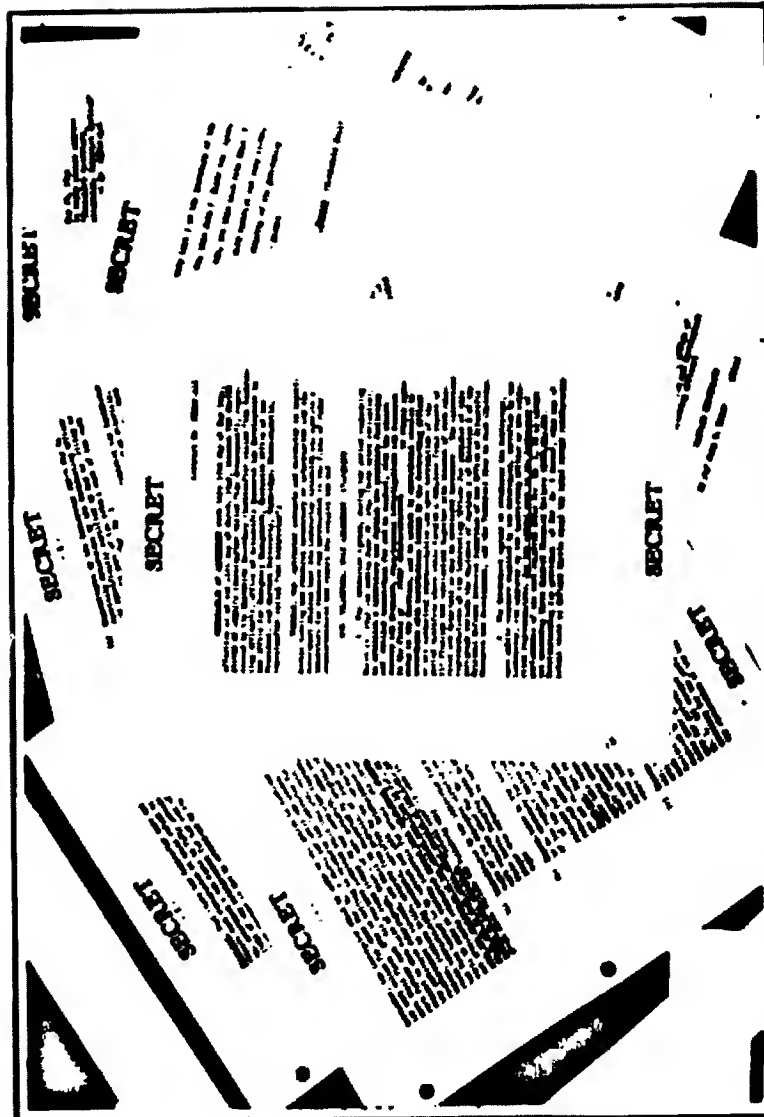


Figure 4. The Radio Research Laboratory's assignment

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well-informed persons felt that the new countermeasures activity would become quite large, and might involve as many as 100 persons in all, or perhaps at the outside, 150. The final strength of the Laboratory was actually five times that amount! However, in spite of the newness of the field, certain broad objectives were apparent from the start. Since radars can be "heard", the need for search receivers with which to detect them was self-evident. One of the very first steps made by the Laboratory was to take over the search receiver development work instituted at the General Radio Company by the Microwave Committee. Dr. D. B. Sinclair, who had been in charge of this work at General Radio, was loaned to the RRL in order to head up the Laboratory's receiver development group. The group's first assignment consisted of developing improved tuning units to take the place of the two-dial units then being procured by the Services. A prototype of an improved unit was demonstrated at the Naval Research Laboratory as early as April, 1942.

It was realized that radars, like any other radio device, could be jammed. However, it was by no means clear how much power would be required to do this, nor was it clear what type of jamming signal would be most effective in accomplishing this purpose. Moreover, it was realized that radar deception by means of false reflecting objects would probably be almost equal in importance to the jamming of radars by means of radio transmitters. Proposals for reflecting devices made out of short lengths of wire, tetrahedrons, etc. were under consideration from the very start.

It was also realized that a good portion of the early effort should be devoted to operational testing, indoctrination and training. For this reason, plans were under consideration from the very start to obtain aircraft for test and demonstration purposes. A well-equipped "Flying Laboratory" would not only make possible studies of the best way to jam radars, but would also assist in connection with operational studies of the effects of jamming.

Important adjuncts to search receivers are pulse analyzers and panoramic adapters by means of which operators can analyze the characteristics and determine the nature of an unknown signal. RRL investigated the existing developments along these lines, and soon came to the conclusion that they were adequate for the job in hand. Effort, accordingly, was concentrated on other problems.

Since it was known that the British had extensive countermeasures experience, the first step in working out a countermeasures development program was obvious. In order to become familiar with British experience and plans, the Director of RRL, together with two key Navy officers in the countermeasures field, flew to England in April, 1942, and carried out a comprehensive tour of English countermeasures laboratories and establishments.

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IV. A SHORT HISTORY OF THE LABORATORY

By the end of May, 1942, Dr. Terman had returned from a six weeks' stay in the United Kingdom. At that time, the Laboratory's total personnel numbered less than 100 persons. Nevertheless, the program was fairly clear: the immediate job was to find out what could be done with radar countermeasures, particularly in the frequency ranges in which enemy radars were known to operate. One Laboratory group tackled the job of designing jamming transmitters for the German "Wurzburg" anti-aircraft fire-control radar frequency range; another went to work on jammers for the lower frequencies in which the German "Freya" warning radar as well as most operational U. S. radar were to be found; a third undertook receiver developments; a fourth tackled the general microwave field, and a fifth studied the effect of jamming on representative U. S. radar systems.

Shortly after Dr. Terman's return from England, it was agreed that random noise modulation was probably going to be the most effective for jamming. Mr. Dyer was asked to see what could be done about developing a better noise source than that provided by the traditional unsaturated diode. Several days later, he had uncovered a new and far more effective noise source (a photo-multiplier tube) and had already put it through preliminary tests. By one week later, the tube had been thoroughly proved and its possibilities were well understood. Tens of thousands of jammers ultimately used this noise source.

Not long thereafter, several experimental low frequency jamming transmitters were completed and tested in the course of flights against representative U. S. radars. An experimental 200 Mc jammer successfully put an SCR-268 radar out of action during a course of tests at Cambridge. Somewhat later, an improved 100 Mc jammer was similarly tested against an SCR-270 early-warning radar at Wright Field with excellent results.

By the end of 1942, the Laboratory had not only been formed and organized, but it had a good share of its growing pains behind it, and could look back upon solid accomplishments. The project had been transferred to Harvard and was well settled in its new quarters in the Biology Building. Additional space was provided by a two-story wooden structure built on the roof of that building.

Actual flight tests had demonstrated that both early-warning and fire control radars could be successfully jammed with relatively low-powered jamming transmitters, and experience had shown it possible to build a jammer of reasonable weight and power drain packaged in a standard aircraft rack. A new and remarkably efficient source of noise energy had been developed in time to be included in the two jamming transmitters (Mandrel and Carpet) which were already being procured by the Armed Forces. Two receiver single-dial tuning units had by this time also gone into procurement - the same two units which proved to be the basis for almost all RCM search work during the war. Also ready for procurement by the end of the year were the Autosearch (AN/APR-2) and Zero-Catcher (RC-164) receivers, although these did not turn out to be as important operationally as the other units. Other important receiver and transmitter developments were nearly ready for procurement at this time: the Rug jammer (AN/APQ-2), and the AN/APR-4, AN/APR-5, and AN/APR-6 search receivers. The latter two receivers were made possible by the development of a satisfactory local oscillator, tunable from 1000 to 3000 Mc for use in microwave superheterodynes.

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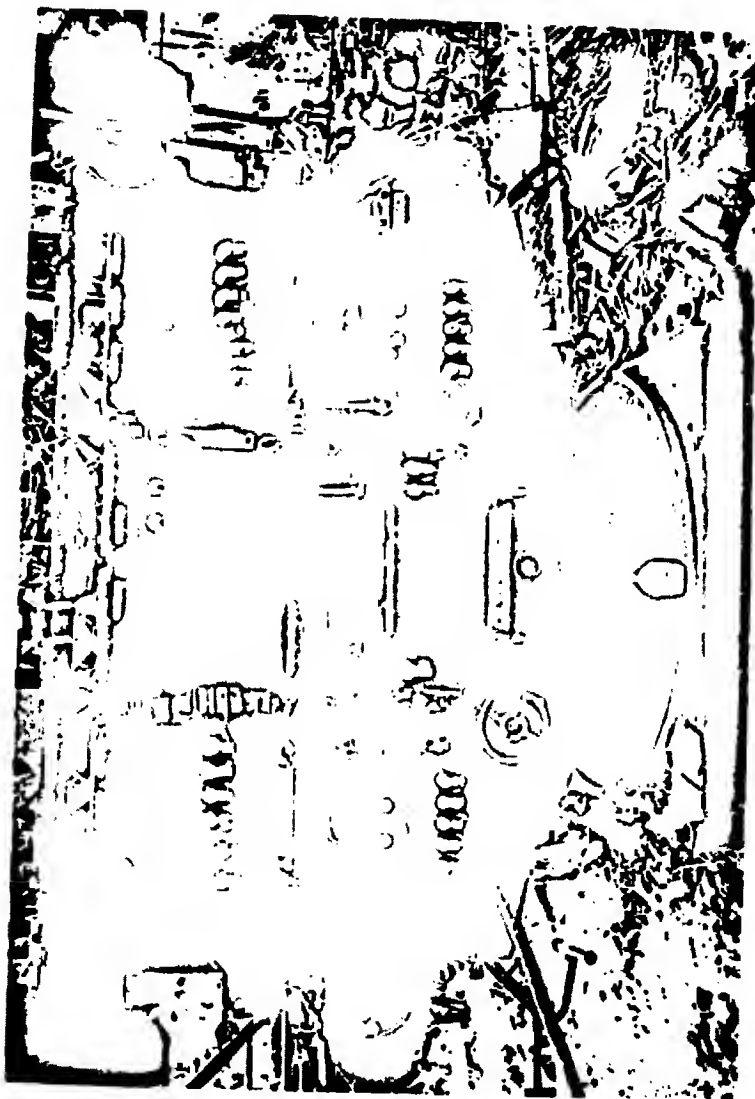


Figure 5. This Japanese copy of the SCR-268 was one of the fire control radars jammed by the B-29's

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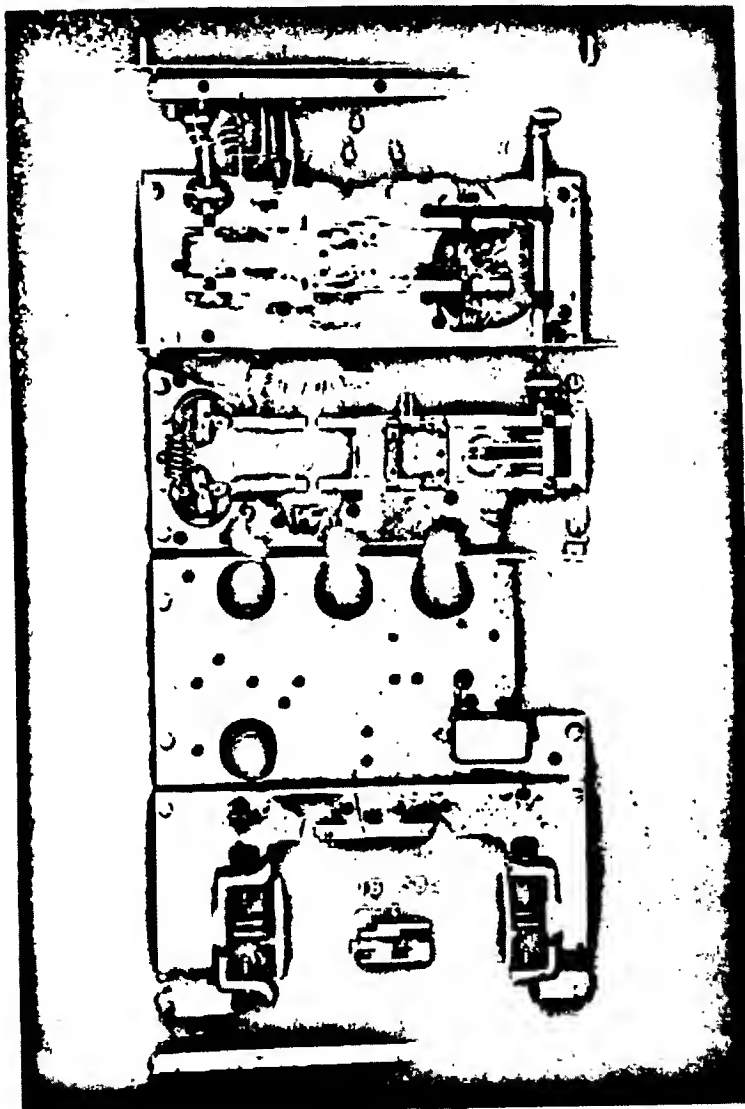


Figure 6. Early experimental Mandrel-type jammer

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As of the first of January, 1943, the Laboratory was at nearly one-half its final strength (in terms of research personnel), and more had agreed to come later. The early difficulties of finding qualified men in the already combed field seemed to be over. The Laboratory had been visited by many important personages in the radar and countermeasures field, and an impression was rapidly growing in Service circles that countermeasures were going to play an important part in the war. Early uncertainties as to the direction of the work were over, and the Laboratory felt itself in a position to evaluate its own program on the basis of the experience it had accumulated. Flight tests of new developments could now be carried out with ease, since by this time the Laboratory had its own aircraft and communications facilities established in a hangar at the East Boston Airport. Moreover, full scale jamming tests were made possible by representative U. S. radars mounted on the Laboratory roof and operated by Laboratory personnel. In November, 1942, the first of a group of RRL engineers were sent to England in order to assist the British and to help keep the Laboratory informed of new developments in the United Kingdom.

Finally, in December, 1942, the first Laboratory-built equipment to be installed in an operational aircraft was being fitted in a B-24 aircraft ordered to scout Japanese radar defenses in the Aleutian Islands.

The events of 1942 set the pattern for what was to follow. The possibilities of RCM had been defined, and the objectives were clearly in view. Early in 1943 the Laboratory's program went into high gear; during the entire year many changes and much expansion occurred. The technical staff doubled in size, while the total of all personnel jumped from 275 in January to 725 in December. In August, 1943, the available floor space was nearly doubled by the addition of a temporary wooden annex to the Laboratory's wing of the Harvard Biology Building.

During the year the large number of developments which went into procurement brought about a natural change in the overall apportionment of the Laboratory's technical effort. As more and more receivers and transmitters came along, a proportionately large effort had to be devoted to designing antennas to go with them. An outstanding antenna development engineer, Mr. Andrew Alford, was obtained to head the antenna group.

The importance of RCM was recognized by the NDRC late in 1942, and Dr. C. Guy Suits was made Chief of an interim "Section F". Early in 1943, Section F became Division 15 of the NDRC, which was made responsible for all phases of radar countermeasures activities. The effect of this consolidation of the RCM effort meant increased support for RRL, and imparted an increased impetus to the work. Dr. Suits encouraged expansion of the overall activity. To him belongs credit for the introduction of a comprehensive countermeasures tube development program which began originally at the General Electric Company and was later extended to other Division 15 contractors. Dr. Suits also deserves great credit for organizing the Division 15 communications countermeasures program. By arrangement with the Army Air Forces, a Division 15 field testing station was set up at Florosa Field, Florida, an auxiliary of the Proving Ground Command's Eglin Field. The Florosa Station was jointly operated by Army and NDRC personnel, most of the latter coming from the Radio Research Laboratory. This station made possible flight tests of RCM equipments under conditions far more nearly operational than was possible anywhere else.

In order to give manufacturers every possible assistance in the rapid production of RCM equipment, the Transition Department, which had been set up in

November, 1943, was greatly expanded and given full responsibility for Laboratory equipments after the original development work had been completed.

In the summer of 1943, Mr. J. F. Byrne was made Executive Engineer of the Laboratory, in which capacity he was responsible for the work of both the equipment-design and model-shop-production groups within the Laboratory. Experience had demonstrated the desirability of building production prototype equipments in a form as close to the final manufactured version as possible. Since all manufactured equipment had to undergo Service acceptance tests, it was found that time could be saved by subjecting prototypes to these tests at the Laboratory, before submitting them to the manufacturer. A Test and Standards Division was accordingly set up by Mr. Byrne and equipped with the necessary shock and vibration testing apparatus, as well as radio and electrical testing gear. Operated as a group entirely separate from the rest of the Laboratory to ensure impartiality, the Test Laboratory provided an important service by carefully measuring and recording the performance of each model before it went to the manufacturer. Although this procedure sometimes delayed delivery of a completed prototype to parties outside the Laboratory, the extra effort paid for itself many times over in cutting down the time required to place equipment into procurement; by making redesign unnecessary, and by avoiding later differences of opinion over performance specifications. The presence of the Test Laboratory also had the effect of greatly improving the design work done by the individual development groups within the Laboratory.

Another important development was the formation, early in 1943, of a model shop production group. Wherever the production of small quantities of equipment must be carried out in the shortest possible time, it is very desirable to have the production agency close to (yet at the same time separate from) the developing agency. It was found that even local model and industrial machine shops were too far away according to this standard; work "farmed out" to them simply took longer to complete. For this reason, a group was set up within the Laboratory to build small quantities of urgently-needed equipment for Service testing, or, in some cases, for emergency use by the Services.

To handle the greatly increased volume of Service project requests which poured in during 1943, as well as to keep the Laboratory abreast of changes in the program, a Liaison Division was created early in the year and charged with responsibility for all relations to the Services. "Informal Liaison Conferences" of RRL and Service representatives, were held at the Laboratory, and did much to coordinate the program by promoting discussions and agreements.

Project requests and information collected through Liaison channels were reviewed by a separate Project Committee that was set up in the spring of 1943 to broaden the basis for technical decisions made by the Laboratory.

The technical results accomplished during the year were many. By April, 1943, only one year after the Laboratory started operating, development of the following transmitters had been completed: AN/APT-1, AN/APT-2, AN/APT-3, and AN/APQ-2, giving a coverage of the radar spectrum from 85 to 700 Mc. Thus by April, the Army and Navy had already placed on order jammers capable of covering the full frequency range used by all operationally important enemy radars during the war! (The crude Japanese S-band equipment was the only enemy radar to be used operationally outside this band.) Moreover, by April, the first production AN/APT-2's had already put in an appearance.

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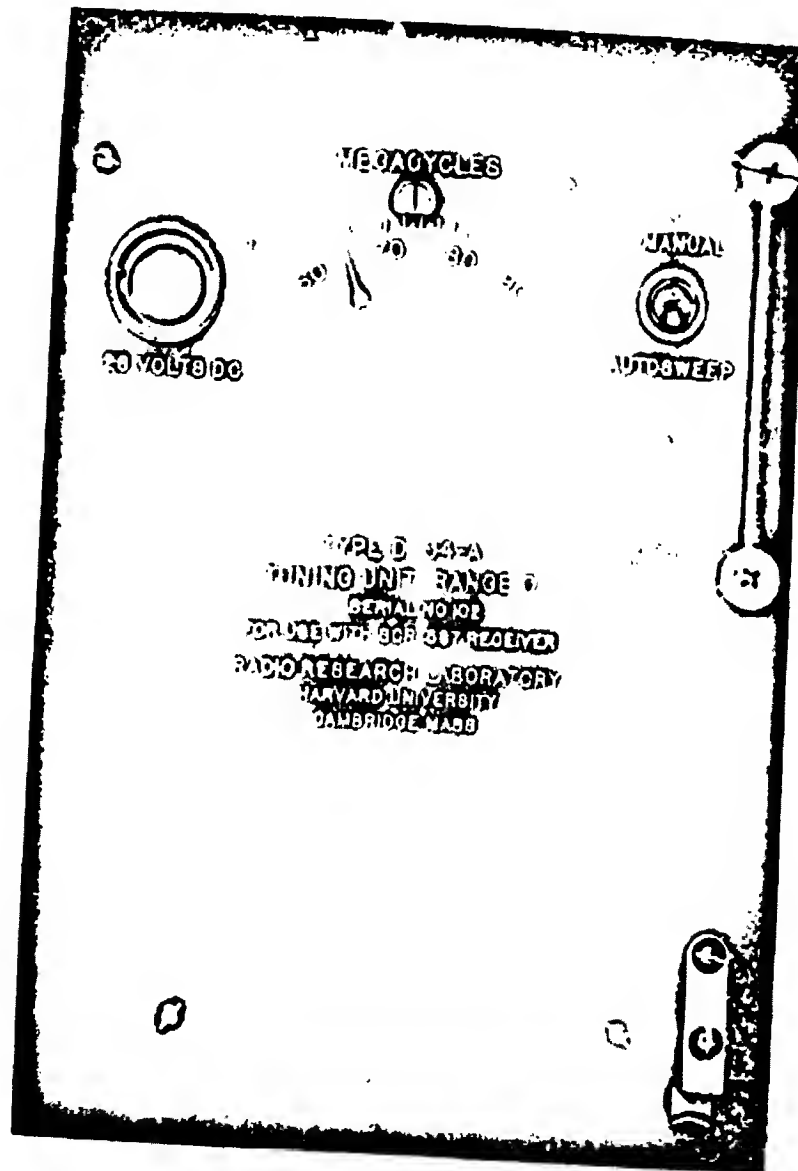


Figure 7. Single Dial Tuning Unit

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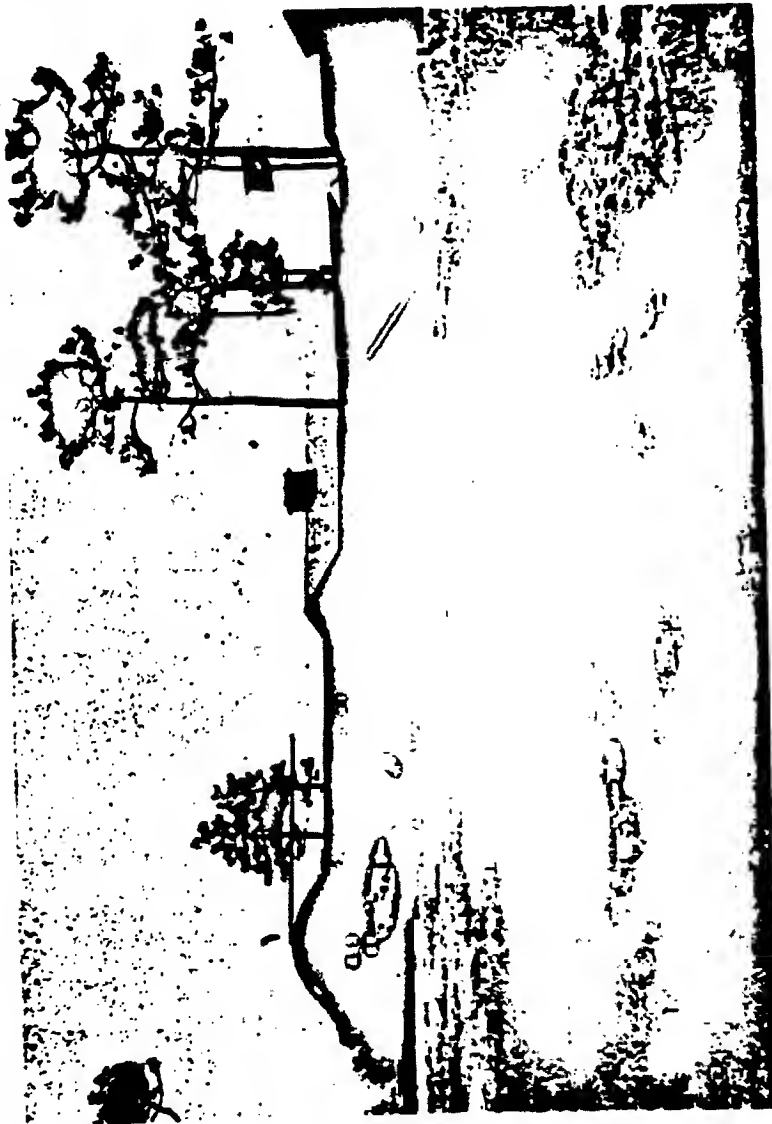


Figure 8. View of Floresa Field; hangar and building used by RRL field group

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The Sloan-Marshall tube - part of a huge electronic jammer known as "Tuba" - startled everyone by producing, in May of 1943, over 20,000 watts of continuous radio frequency power at 500 Mc, or about 1000 times the highest level reached before that time. Ordered by the British under Lend-Lease, the Tuba equipment was intended to lay down a jamming beam over Germany in which homeward-flying RAF bombers would be free from attack by AI radar-equipped German night fighters. The achievement of such a remarkable power output caused a veritable revolution in thinking, and exerted a marked influence on the later course of the Laboratory's technical program. As for receivers, the AN/APR-1, AN/APR-4, AN/APR-5, and AN/APR-6 search sets were completed and placed in production in the first part of 1943.

By April, 1943, the first significant operational results had been obtained with RRL-developed RCM equipment. The "Ferret I" plane had spotted Japanese radar on the Aleutian Island of Kiska, and had identified two potentially dangerous equipments.

Meanwhile in Europe, the wisdom of building model-shop equipment for Service testing, as well as sending scientists abroad to assist with its introduction, had begun to pay off. With the help of a U. S. scientist stationed at a British laboratory, the 8th Bomber Command carried out experiments to see if the German anti-aircraft radar was being used against their daylight B-17 formations. The positive evidence provided by these tests, together with good results obtained by an operational trial of a model-shop constructed Carpet transmitter, led to the formulation by the Eighth Air Force of the requirement that one Carpet transmitter be installed in each replacement heavy bomber sent to that theater.

In April, 1943, Dr. Donald B. Sinclair, at that time head of the Laboratory's receiver development group, accepted an appointment as Technical Observer to accompany the first of a series of Ferret planes which were sent to North Africa and later Italy to help the Army Air Forces in those theaters pinpoint the many German radars known to be dotting the northern shores of the Mediterranean. Dr. Sinclair's field experience had a very significant effect on the Laboratory's program: it greatly raised the priority on the development of direction finders as against homing devices, and it lowered the priority on warning devices such as the Zero-Catcher, in view of the lack of an operational need. As a result of Dr. Sinclair's work, and the work of the technical observers who succeeded him, the Mediterranean Theater for a considerable period was perhaps the best informed and best educated in the field of RCM. As a result of the interest shown, the MTO was the first theater to request and receive production models of the RRL-developed single dial tuning units. Furthermore, the first production Rug jammers were flown to the Mediterranean theater and used at Salerno during the invasion of Sicily (in September, 1943) when the U. S. Navy used jammers for the first time.

An early realization of the importance of scientific assistance to the Services in the field, led in May, 1943, to discussions in England sponsored by the U. S. Radar Mission, at which a proposal to set up an RCM laboratory in the European theater was made. By September of that year arrangements had been completed and the American-British Laboratory of Division 15 (ABL-15), in accordance with a contract between Harvard University and the NDRC, was operating at Malvern, England, on premises supplied by Britain's chief radar and countermeasures laboratory, the Telecommunications Research Establishment. Entirely U. S.-controlled, and set up at the request of the U. S. Army Air Forces, this laboratory nevertheless was able to serve all branches of the U. S. Services in the ETO. Its work was not limited exclusively to radar countermeasures; communications and

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411-299

guided missile jamming activities were undertaken as well. ABL's staff, although largely recruited from RRL, included several men on loan from other Division 15 laboratories, and totalled some 70 persons at its peak.

RRL assisted the Army Ground Forces on two occasions in 1943. In July, a ground jamming expedition was sent to the Aleutian island of Amchitka, from which point the radars on Kiska were to be put out of action during our invasion of that island. The radars to be countered, however, were destroyed by the Japanese during their evacuation of Kiska several days before the invasion. In November of 1943, plans were laid for a second ground jamming expedition, this time to the island of Corsica in the Mediterranean. Jammers for this expedition were crash-produced at RRL, and two laboratory technical observers accompanied the equipment to the theater. This second expedition proved to be somewhat disappointing from the laboratory's point of view, since on arriving in the theater the expedition found no satisfactory operational plan worked out for the use of the equipment. It was necessary to wait eight months before the jammers could be turned on.

Later in the year, intelligence reports of a possible German radar development for submarines gave rise to an urgent Navy request to the Laboratory for the crash production, and installation in a Navy sea search PB4Y-1 plane, of Laboratory-built prototypes of the AN APA-24 and APA-17 direction finders. These installations were completed in slightly over one month's time at the Laboratory's newly-acquired airport facilities located on the Army Air Base at Bedford, Massachusetts. The plane, known as Albatross II, was sent directly from Bedford to an operating base in North Africa, from which point it carried out over a hundred patrols over the submarine hunting grounds in the Mediterranean area. All equipment functioned perfectly, but no submarine radar signals were ever heard, and it was concluded that although the submarines undoubtedly had radar, they were evidently not using it, a fact which was confirmed by post VE-Day intelligence.

As a result of the satisfactory performance of the equipment, the Navy eventually ordered over 1000 APA 17's for the special search planes described in the next paragraph.

Started somewhat before this Albatross II expedition, was another Navy airborne radar search project known as Albatross I. Early in 1943, the Bureau of Aeronautics asked RRL to participate in the mock-up and testing of a new long range reconnaissance aircraft for the Pacific theater. Known as the PB4Y-2, this plane differed from the B-24 in that the fuselage was lengthened by some 6 feet in order to house a remarkably well coordinated installation of the latest in radio, radar, and RCM equipment. RRL supplied engineering assistance on this project from the very first, even when the aircraft itself was largely in the blueprint stage. Over 800 Albatross planes were ordered by the Navy (of which 600 were delivered), and a considerable number were in active Service in the Pacific by the time the war ended.

The highlight of the year, as far as the operational use of countermeasures is concerned, was the successful introduction of Carpet anti-aircraft fire-control jammers in the European theater on October 8, 1943. Carried in 68 aircraft of two groups of the 8th Air Force during a raid to Bremen, the Carpets resulted in a 50% reduction in losses for the protected groups. Use of Carpets was closely followed by the introduction of Window, which had first been employed by the British in July, 1943.

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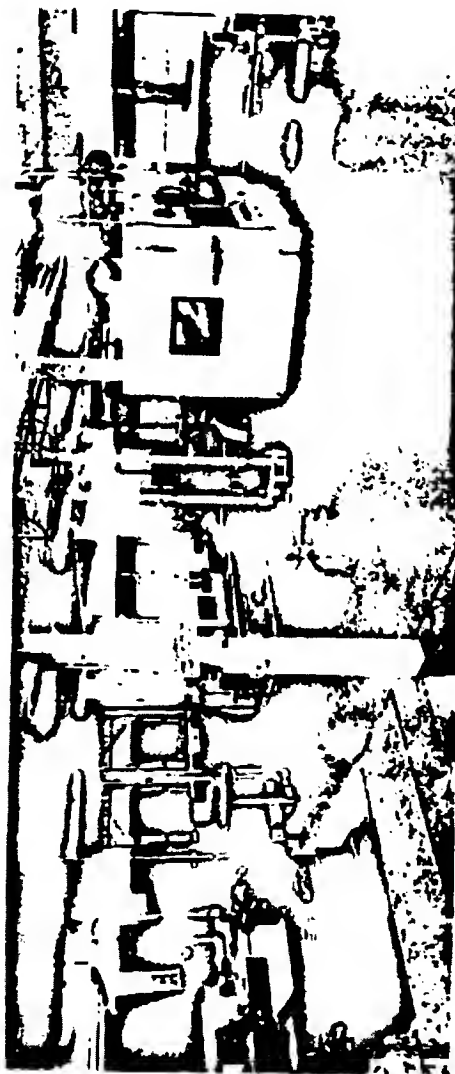


Figure 9. Test Laboratory; shake table at left; cold chamber at right

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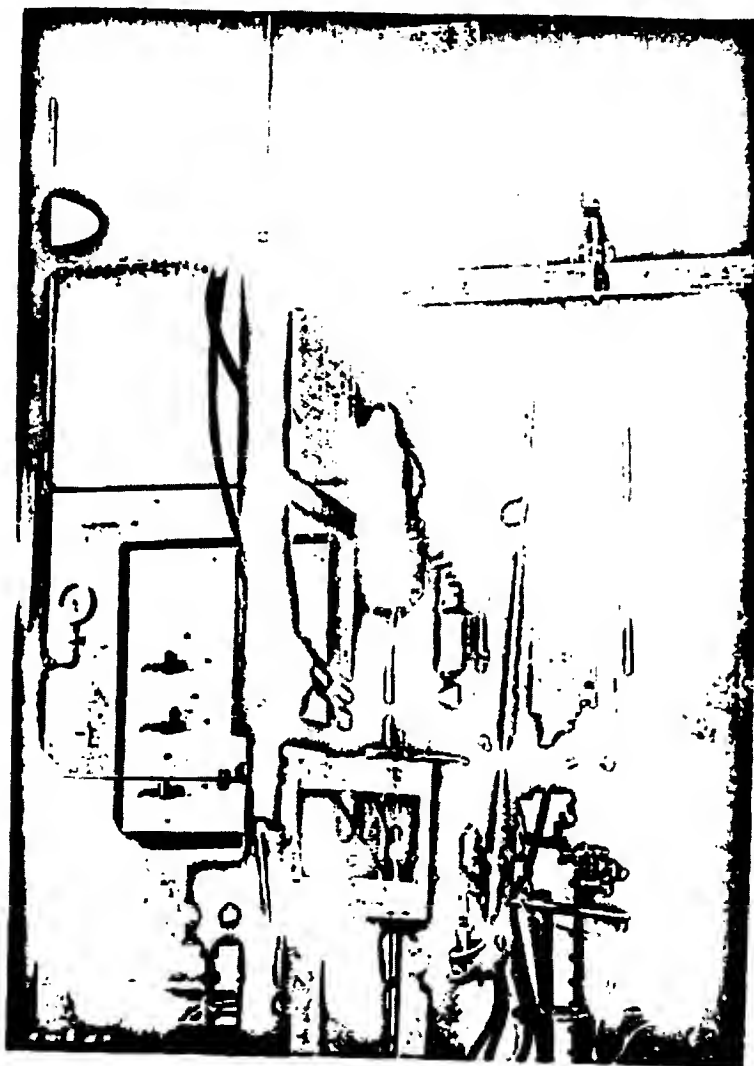


Figure 10. Tuba: 500 megacycle arc at 50 kw power level

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By the time the American Air Forces in Europe began using Window, this countermeasure had been very considerably refined and improved as a result of studies at the Radio Research Laboratory. These indicated that narrow Window strips were the most efficient when the band of frequencies to be covered is not large. The quantity production of this narrow Window was made possible by a rotating cutter designed by Mr. Harold Elliott. In May and June of 1943, a number of these cutters were constructed on a crash basis by the Laboratory, which undertook at the request of the Signal Corps to make available a small production facility in the shortest possible time. A small Laboratory production shop was set up in which the performance of the new machines could be tested and new ideas tried. A stock of Window for Service testing and for use as a reserve in the event of an urgent operational need, was accumulated as a by-product.

Early in 1944, the need for expanded field assistance to the Services was clearly recognized, and as one aspect of this, greater support was given the overseas laboratory, ABL-15. Mr. J. N. Dyer was made Director of the laboratory; and its size was steadily expanded until by the end of 1944 its personnel numbered in the 60's. It was found that a laboratory of this sort, operating in a foreign country, required a larger administrative staff than had at first been considered necessary. Additional high caliber administrative personnel were made available to ABL, and a very gratifying increase in the Laboratory's effectiveness resulted.

In addition to the very considerable help which ABL rendered to the Air Forces in 1944 in connection with their greatly expanded Carpet program, the Laboratory also assisted the Tactical Air Forces and certain ground units operating on the Continent. In October of 1944, the establishment of a Continental advance base was requested by the Army and undertaken by ABL-15.

In February, 1944, Tuba was ready for shipment overseas. Mounted in 7 huge Army trucks, each of which was completely encased in a watertight case for deck-loading on a transport, the Tuba equipment weighed more than 170 tons and was said to have been one of the largest single shipments ever to leave the port of Boston.

Installed at a site on England's south coast, the two 25-kilowatt transmitters were ready for operation by mid-July, 1944. By that time, however, the German night-fighters were no longer a serious problem, and in addition, a change was made from the Lichtenstein AI radar to the much lower frequency SN-2. If the Germans ever had any doubt about the desirability of making this shift, the first blast from Tuba must have convinced them!

Early in 1944, however, the British had ordered two more Tuba equipments which were built under a Division 15 contract with the Delta Star Electric Company. These additional units were delivered by the end of 1944.

An urgent Navy operational requirement brought the war close to RRL in March of 1944. At that time the Laboratory was engaged in the crash production of some 50 AN/ARQ-8 transmitter-receivers, designed originally for low frequency radar or communications jamming, and being procured by the Army Air Forces for the latter application. However, the menace of the German radio-controlled high-angle and glide-bombs (types FX and Hs-293) to our Naval operations in Europe, brought about an urgent request from the Navy for diversion of 30 of the Army's ARQ-8's for use aboard the smaller ships as guided missiles jammers. The ARQ-8 equipments could easily be modified for this job, and were particularly desirable in view of their ease of operation, light weight, and compactness. Completion of the first 30 sets was expedited and the necessary changes incorporated in

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411-299

record time. The equipments were delivered by truck directly from the Laboratory to Navy Yards in the vicinity of Boston and New York and there installed aboard destroyer escorts, destroyers and cruisers - a job which required close coordination in view of the fact that these ships were in port, in most cases, for a few days only - seldom more than a week. Moreover, during this time an average of over 4 members of each crew were given training at RRL in the use of this new equipment.

The AN/ARQ-8 jammers saw operational use in the invasions of Normandy and Southern France. It is also interesting to note that some of these equipments, crash-produced and installed by RRL in the U. S. A., were given their pre-invasion tune-up and operational check in England by members of the Radio Research Laboratory serving overseas.

In the European theater, as the date of the Normandy invasion drew closer, it became apparent to those responsible for the planning of the invasion RCM program that the installation of U. S. equipment aboard British ships would not be completed in time, owing to a shortage of qualified British engineers. As a result of this emergency, a cablegram was sent from General Eisenhower to General Marshall requesting that the latter personally contact OSRD and ask that sixteen American scientists be sent to England on the highest possible priority. Four days after receipt of this message, eleven of these men (fourteen of whom had been selected from RRL and two from CBS) arrived in England, and the remainder followed within four days, having travelled overseas on a No. 1 air priority. As a result of this U. S. help, 90% of the projected installations were completed by D-Day.

Shortly after this "Petticoat" expedition left, disturbing news was received by the Laboratory from the European theater. According to all available information, Carpet transmitters, although in quantity production in the U. S., were not being received overseas. As a result of inquiries made by RRL a little earlier, a member of the London OSRD mission had carried out an investigation of the situation, and now reported back that a continuing shortage of Carpets was resulting in a considerable loss of morale on the part of the Air Force Groups using this equipment. So few were available, that a complete barrage of the spreading German radar frequencies was out of the question, and the air crews were becoming discouraged at the possibilities of this countermeasure.

Mr. A. E. Cullum, Jr., an Associate Director of the Laboratory, had accompanied the "Petticoat" expedition to Europe. He promptly investigated the situation and started a chain of happenings, described below in greater detail under Liaison, with the result that a tremendous flow of Carpet equipments was started on its way to the European theater. These began to arrive in September and by December, 1944, over 6000 had been installed. Procedures for the installation, testing and operational use of these equipments on a large scale were worked out on the spot, and a comprehensive program of air crew training was established, all with the aid of ABL-15.

Valuable assistance in the overall direction and organization of this program, was also provided by an ABL-15 scientist on loan as a consultant to the Operational Analysis Section, 8th Air Force. Based on engineering considerations worked out in consultation with ABL, operational plans and "Standard Operating Procedures" were prepared and promulgated to the many Air Force groups using the Carpet transmitters. Since a considerable German reaction resulted from our countermeasures effort, the Carpet program required constant supervision. For example, it was necessary to organize and carry out continuing studies of enemy frequency

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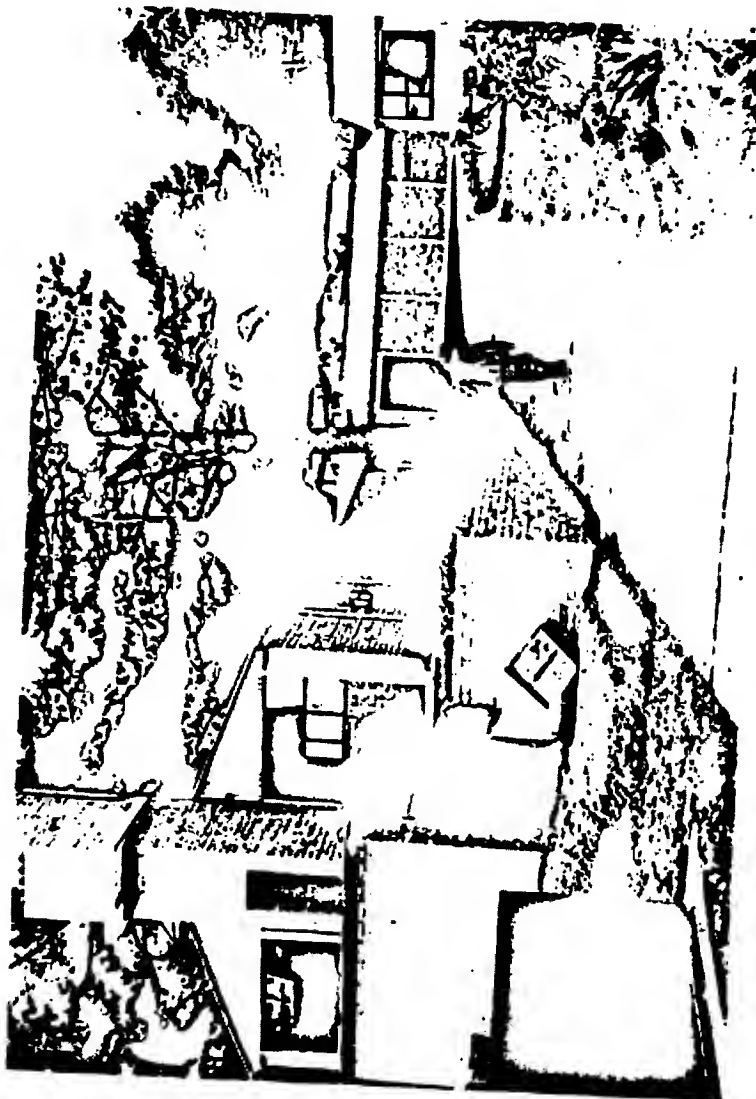


Figure 11. Buildings of the American-British Laboratory

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Figure 12. Prototype PB4Y2: countermeasures antenna blisters under nose

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distribution in order to enable our forces to set their transmitters properly and use them efficiently.

By the summer of 1943, the Radio Research Laboratory and in particular Mr. A. E. Cullum, Jr., Associate Director and Head of Transition, became convinced that Radio Research Laboratory could best serve the theaters of operation and the procurement agencies of the Army and Navy by a definite and consistent model production program whereby the Laboratory itself would either build a given number of models of each equipment expected to go into quantity Service procurement, or would have them made by an outside contractor.

Some of these models would be retained by the Laboratory for field testing purposes, some would be allocated to the various Service testing agencies in this country, and some would be allocated to theaters of operation. The advantages of a systematic program of this sort were many. In the first place, production of 20-25 units of a development gave valuable experience in ironing out production difficulties. Second, an adequate supply of models greatly facilitated the work of Radio Research Laboratory and Service field testing groups, which thereby had a chance to evaluate the performance of each new equipment before plans for large-scale production were frozen. Third, allocation of models to the operating theaters helped educate field commanders in the possibilities of the new equipments, and made it easier for them to formulate the operational requirements needed by procurement agencies at home to schedule final Service production.

At the time of the original discussions of this model procurement program (which in effect organized and formalized model production which had previously been carried out from time to time), it was plain that the Radio Research Laboratory would be unable to build a sufficient number of models of each development in its own model shop. This made it necessary to develop a system whereby these models could be obtained on sub-contracts. In view of the large expenditure of funds that would be involved, the procedures and contract forms to be used were reviewed very carefully with OSRD. However, it was important that the model procurement program proceed on a large scale immediately, even during these discussions, and without testing out on a small scale, the procedures that were involved. The first sub-contract under this procedure was let in August, 1943, and from that time on, the activity expanded very rapidly. The models produced were worth many times their value to the program as a whole, and the program fully lived up to the original expectations.

In order to maintain closer touch with the countermeasures needs of the theaters, the Army Air Forces instituted, in May of 1944, at the suggestion of Mr. Cullum, a series of teleprinter conferences with overseas headquarters. Both RRL engineers and RRL field representatives participated in these conferences. The first of these was with the Air Force headquarters in England. Later on, conferences with headquarters in the Mediterranean area, and still later with Guam and Manila, were begun. These made possible a far better coordination of the overall program, since they gave those at home a clear picture of theater needs, and at the same time provided the theater with the latest information on U. S. plans and developments. Even more important, they made it possible to get rapid action by clearing up problems and exchanging views informally.

The remarkable success scored by our armies in Europe in the fall of 1944 led to a feeling of optimism on the part of the OSRD as well as others. Plans for the demobilization of the Laboratory, in the event of victory in Europe, were worked out as a result of the OSRD demobilization plan, and made ready in case they were

CONFIDENTIAL

411-299

needed. Although no official encouragement was given, a few engineers left the Laboratory at this time. The stalemate in the late fall of 1944, and the incident of the "Belgian Bulge" in December of that year, brought all of these plans to a standstill, however, and caused a considerable change in thinking.

The year 1945 began inauspiciously as far as the Radio Research Laboratory was concerned - with the death by enemy action of Wallace B. Cauffield, Jr. on New Year's Day. Stationed at ABL and serving as a Technical Observer in France for the 9th Air Force, Cauffield lost his life during a strafing attack on a column of American vehicles. He was posthumously awarded the Bronze Star.

The first part of 1945 brought a gradual tapering off of the Laboratory research activities, and a gradual change in the overall emphasis of the program. Continuing indications of possible enemy use of centimeter radar led to further technical developments in this field. The AN/APQ-20 airborne microwave jamming system was further refined and was given the nomenclature AN/APQ-27. Recovery of a Japanese shipborne 10-centimeter radar from a cruiser sunk during the action of Leyte Gulf in the Philippines gave impetus to a Navy project which had been under discussion since early in the year. A satisfactory 1-kilowatt centimeter tunable continuous wave magnetron operating at microwave frequencies had been developed; this was incorporated in the design of a shipborne jamming system embodying the very latest engineering practices. The project, begun in February, was code-named "Elephant" in view of its large scale. Intended for use on the larger Naval vessels, the "Elephant" project represented the development of a complete spot jamming system, with a transmitter capable of being remotely tuned, a completely new receiver having high image rejection, and other features incorporating the entire experience of the Laboratory up to that date.

New presentation equipment for setting the transmitter on frequency was devised; new directional transmitting antennas that could be trained by the counter-measures operator were worked out, as well as special receiving aerials for look-through, general search, etc. The jamming operation had to be satisfactorily integrated into the use of standard radar direction finders such as the DBM. Along with all this, a large systems engineering job was required in order to make Elephant into a unified system, which could function without disturbing the operation of adjacent friendly radars. Moreover the entire jamming operation had to be closely tied in with the ship's Combat Information Center. Completed shortly before the end of the Japanese war, the "Elephant" was installed for test in September, 1945, aboard the U. S. S. Asheville, where it performed its anticipated function with great success. It provided satisfactory jamming cover against shipborne centimeter search and fire-control radar, giving protection at ranges far shorter than the minimum required.

In the European theater, responsibility for the administration of the activities of RRL Technical Observers in the Mediterranean area was transferred to ABL-15 in the Spring of 1945, since it was found that the needs and requirements of the two theaters were very similar. This made possible the better coordination of operational planning, and through an interchange of manpower, a rendering of greater assistance to the somewhat understaffed Mediterranean area.

In the Pacific theater, effective Japanese anti-aircraft fire-control and searchlight-control radar was encountered by our forces attacking the island of Formosa, the Manila area in the Philippines, and mainland of Japan itself. This led to the introduction of a full-scale 200 mcgacycle jamming program by the Strategic Air Forces, and caused a larger degree of attention to be focused on this theater in 1945

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CONFIDENTIAL

411-299



Figure 13. Early B-17 Ferret planes at Foch Field, Algiers

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411-299



Figure 14. AN/ARQ-8 guided missiles jammer installed aboard a destroyer

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411-299

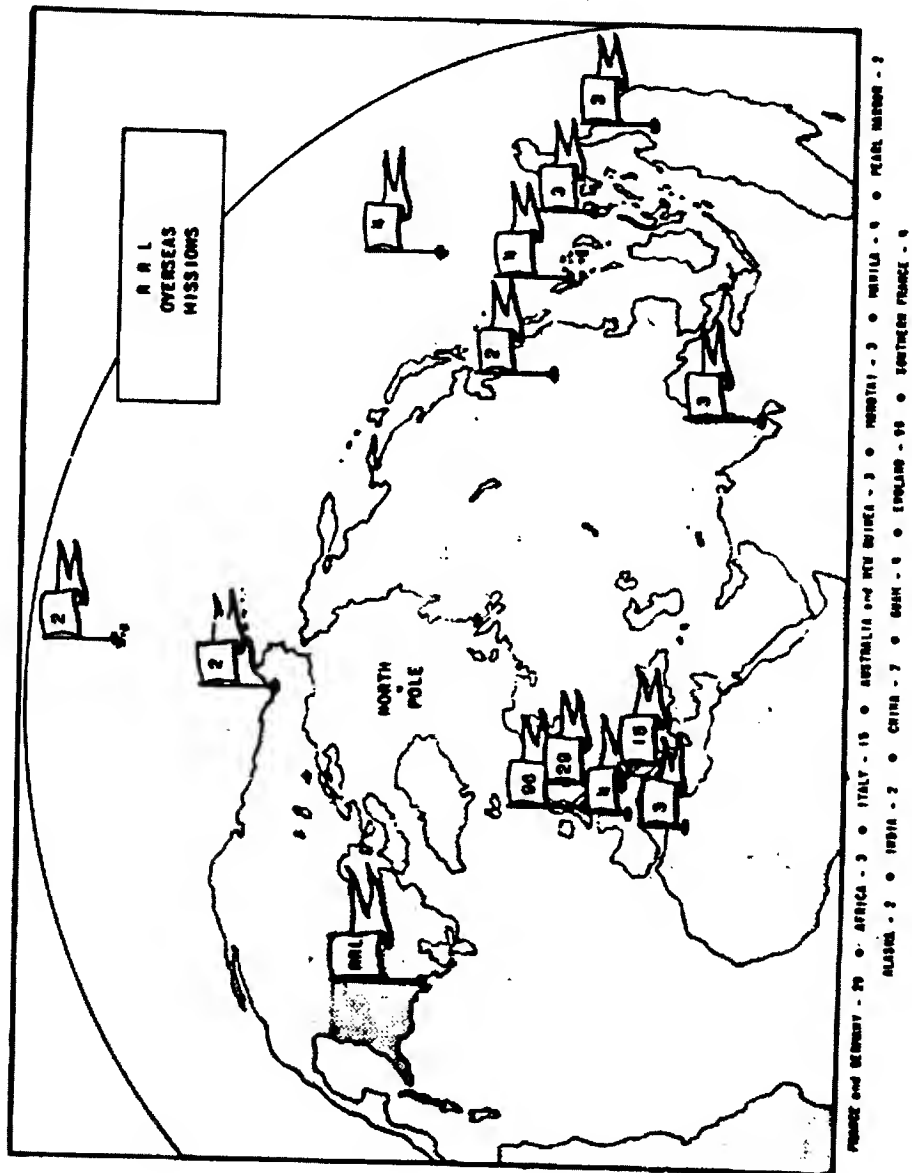


Figure 14A.

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than had been the case before. The number of RRL Technical Observers assigned to the Pacific increased very sharply in 1945, and rose to an all-time high of 16 in March and April, at which figure it remained until the end of the Japanese war.

Consideration was given to the desirability of establishing a Pacific RCM laboratory similar to ABL-15 in England. By the end of the Japanese war, active plans were being laid for an RRL RCM group to be stationed at a proposed OSRD - sponsored laboratory in Manila.

The Informal Liaison Conferences, which in 1943 and 1944 had helped to put Laboratory personnel more closely in touch with Service thinking and Service requirements, had by this time served their purpose, and were replaced in the summer of 1944 by a series of meetings held at more or less regular intervals in the Washington hotel bedroom of Mr. A. E. Cullum, Jr. At these "smoke-filled sessions", key members of the Laboratory took part in informal discussions with Service officers responsible for the RCM program. These meetings served a useful function in keeping all concerned abreast of the latest developments and in helping to clarify the problems of the moment.

The end of the European war found ABL-15 well prepared for a speedy termination of its activities. Its physical plant was returned to the Telecommunications Research Establishment, and most of its equipment was turned over to the Signal Corps. All personnel had returned to the U. S. by early July.

The end of the Japanese war in August put into effect plans already worked out for such a contingency. A conference of all Service representatives interested in the RRL program was held at the Laboratory on August 23, and the disposition of the Laboratory projects active at that time was informally decided upon and later confirmed officially. Certain projects for which there was no further need, were terminated immediately. Other activities which were near completion and which had continuing values were completed in order to preserve those values. Arrangements were made to transfer still other projects to the Services, either immediately or when a convenient and close-at-hand stopping-point was reached. Nearly all Laboratory work was discontinued by the first week in October, although a few projects continued active until November 1, 1945. On that date all research work was stopped, and from that time until the end of the Laboratory's existence the efforts of the remaining Laboratory scientific personnel were entirely devoted to the preparation of reports. By 1 January 1946 the size of the Laboratory had shrunk to about 230 persons of whom less than 10% were scientific personnel.

CONFIDENTIAL

V. TECHNICAL ACCOMPLISHMENTS

The following section is a review of the highlights of the Laboratory's technical program.

Window

One of the simplest of radar countermeasures are the thin strips of metal foil known as Window. Yet this seemingly obvious idea was one of the most closely guarded secrets of the war. The British had found, experimentally, that sheets of aluminum foil, when dropped from planes, were capable of giving a sizable radar echo. On the other side of the Channel, the Germans had also discovered this fact. Both sides considered the possibilities of these simple confusion reflectors so potentially dangerous, that experimental work was curtailed and the idea held in great secrecy lest it be found out.

At the time of Dr. Terman's visit to England in 1942, the British had done a great deal of experimental work with their foil sheets, some of which bore printed inscriptions in order to deceive the enemy into thinking that they were propaganda leaflets. Many empirical tests had been made, in which the echo from the sheets of foil had been compared with echoes from aircraft as viewed on many different radar systems. However, although a vast body of experimental data was at hand, no real theoretical study had been carried out in England, owing to the shortage of qualified scientists.

In view of the promise shown by the idea, an experimental program was begun at RRL. A number of different possibilities was considered, and tried out against actual radar systems. At the same time, through the courtesy of the Radiation Laboratory, a well-qualified physicist (Dr. L. J. Chu) was loaned to RRL and given the assignment to carry out a thorough theoretical study of the Window problem.

Not long after RRL first engaged in the field of Window research, the Laboratory was requested by the U. S. Navy to drop further experimental work on this countermeasure, for security reasons. The theoretical work was, however, carried to a conclusion, and shortly thereafter, when the security situation relaxed, experimental tests were resumed in Cambridge. In January, 1943, one of the RRL's scientists, Dr. Fred L. Whipple who had been hired to work on operational analysis problems, was asked to turn his attention to Window. After studying Chu's analysis and the British experimental work (which proved to be consistent with this analysis) he quickly grasped that the most efficient way to use the metal foil was to make the Window strips really narrow, particularly when the radars to be countered were concentrated in a frequency band of limited width. This was exactly the situation in the case of the German Wurzburg anti-aircraft radars.

How to make the narrow Window strips in quantity then became the problem. It was known that approximately 2000 strips were required in a single bundle in order to return a sizable echo. In order to give narrow strips adequate mechanical stiffness, it was necessary to give them a lengthwise crease. The problem was to manufacture this "bent" Window on a practical basis; it was put up to Mr. Harold Elliott, a mechanical designer of wide experience. A new type of Window cutter was soon devised, similar in principle to a milling cutter or lawnmower. By making alternate blades dull, the proper crease could be added to the center of each strip. By May, 1943, a prototype Window cutter had been built and successfully operated

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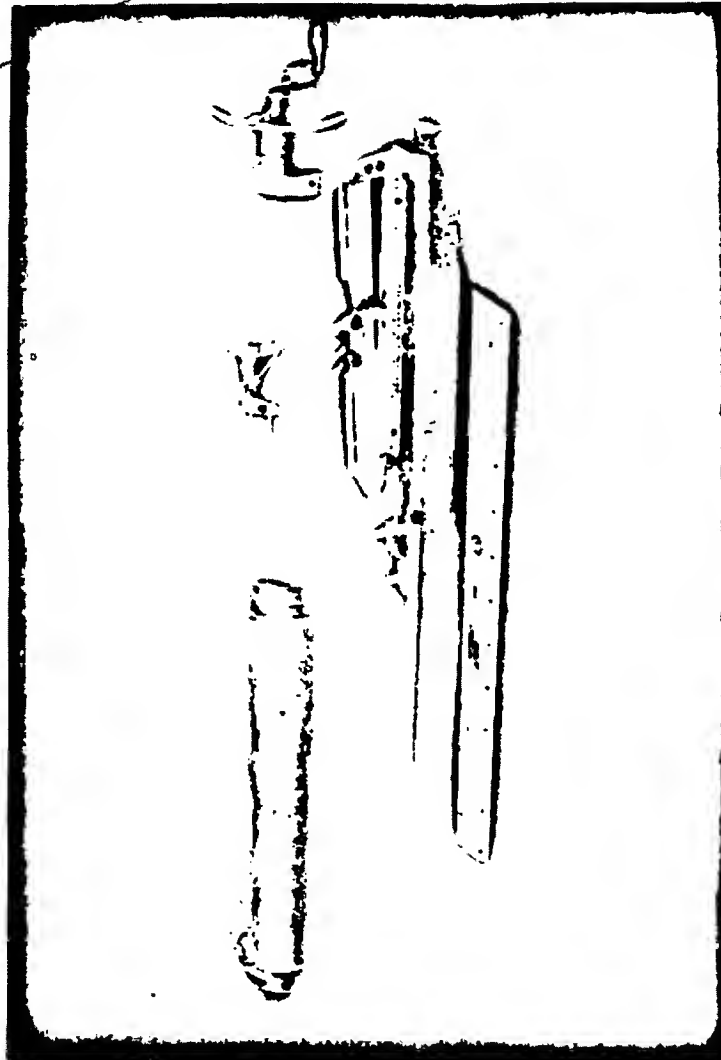


Figure 15. 1000-3000 megacycle lighthouse tube local oscillator for AN/APR-5

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411-299

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RRL No. 12804

ALLOCATION OF RRL EQUIPMENTS

IMPORTANT NOTE: This equipment is in constant use and subject to very change and the equipment is offered to the organization named. After that, and prior to the receipt of a request from that organization, the equipment may be reallocated if the situation arises to require it. After a request has been accepted, however, reallocation of that equipment normally will be made only to extreme instances. This chart is for your personal use. It is not to be discussed with anyone without consent of the RSI, Treasuries Office.

EQUIPMENT DESCRIPTION: Twin Stick Antenna System 150-210 Hz. (Includes M2002 Solenoid)

44-245-56/47-82-241

QTY	DESCRIPTION	DATE	QTY	DATE
1	AKI		1	3/23/44
2	WFO	Reichman/Halla	2	1/2/45
2	WFO		1	1/16/45
2	WFO		1	3/24/44
2	AKI	3/22/45 Haller/Harris (1)	1	3/23/45 HOLMES
2	AKI	7/26/45 TPI AKI/Hingston (1)	1	8/9/44
2	WFO	3/24/45 Clark/Harris	1	4/28/45 HOLMES
2	WFO	3/26/45 Jones/Harris	1	3/23/45 HOLMES
2	WFO	Jones/Halla	2	3/23/45 HOLMES
2	WFO	3/26/45 Jones/Harris	2	4/20/45
2	AKI	Instrument Stock - 2		
		Transaction Stock - 2		

REMARKS: *25 purchased from Watson Co. on SC55. 4 extra K2802 Baluns purchased from them on SC55 and F.O. 4174. Six Antennas are part of those procured from Comfild procurement on SC 60 and F.O. 4180.

Singapore

Transmission Engineer

Dist. No.

on. C. G. Borne (White) N P Bame (Caucary) Alteration Date: 5/25/48 R.F. No: 700
D. S. Kames (Blue) E. R. Aimer (Green) Supervisor: 1/12/48
A. E. Oslawa (Pink) 6/25/44 REL No: 32904

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Figure 16. Representative Model Allocation List

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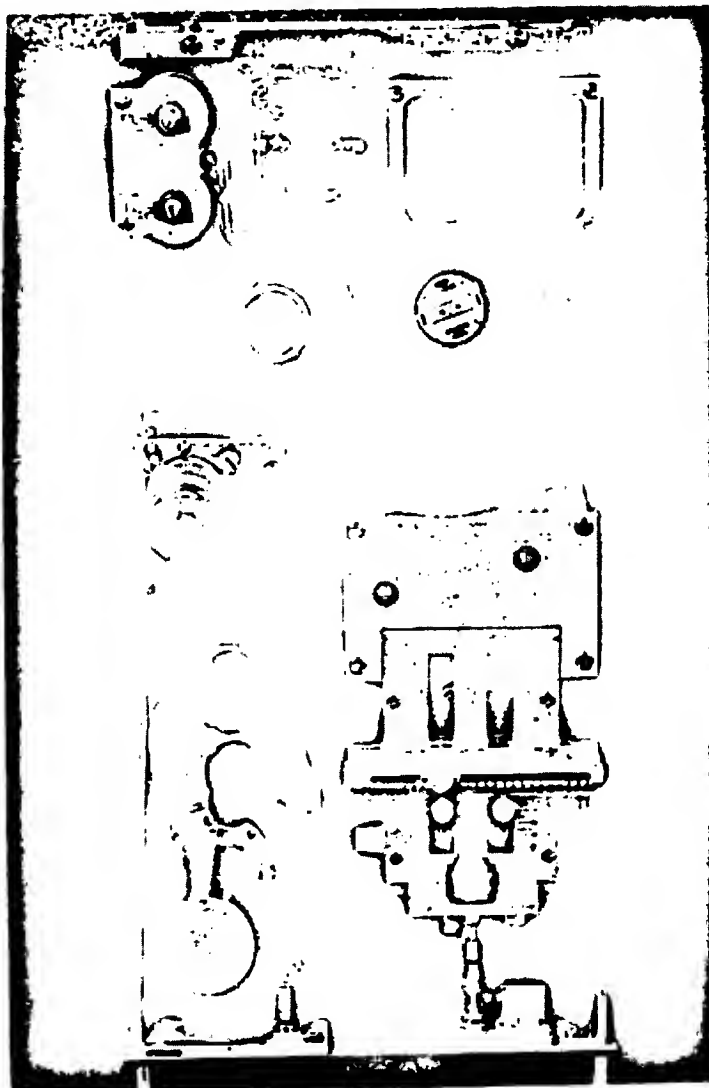


Figure 17. Top view of the Carpet I transmitter

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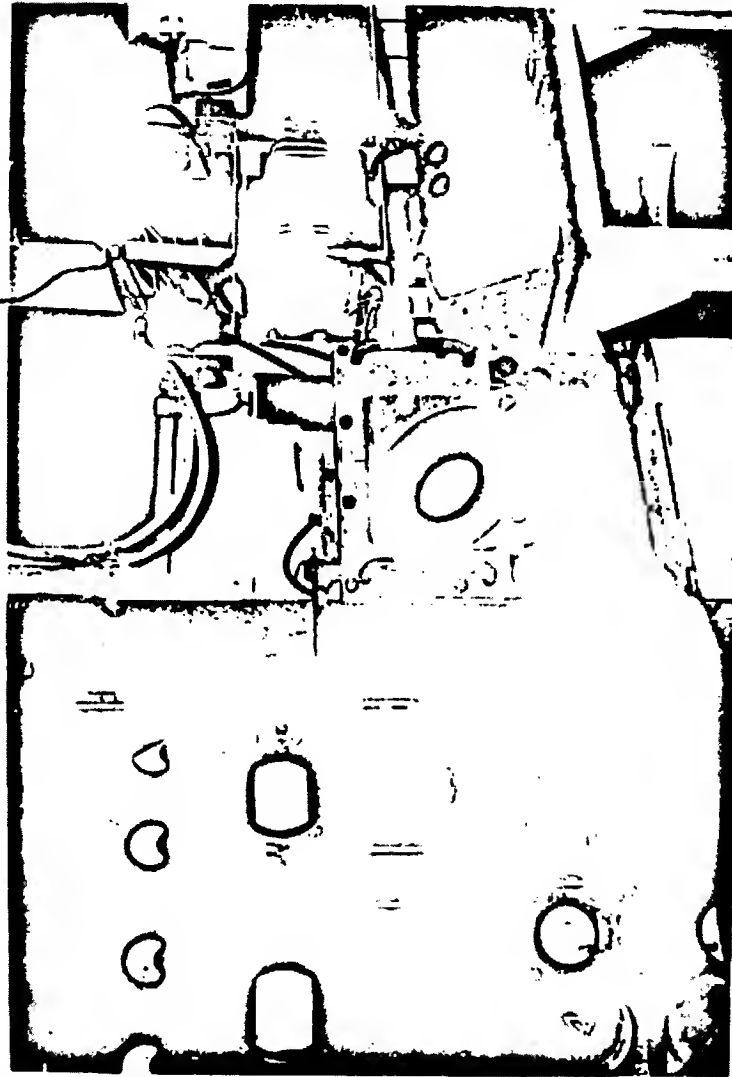


Figure 18. Elephant aboard the U.S.S. Asheville: receiving position

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at the Laboratory. Previous to that time, field tests of Window had employed only small quantities of material, which had left only isolated pips on the screens of the radars affected. A full scale test, employing large quantities which completely saturated an area, were now made possible. The results were striking, and motion pictures of the tests created the greatest interest in Service circles. Those concerned with the RCM program were given an entirely new idea of the possibilities of this countermeasure. Window was seen to be not merely a deceptive device, but a countermeasure almost as effective as jamming. Tracking an aircraft through the infested area was completely impossible.

Immediate action was taken by the Signal Corps. The Laboratory was asked to develop facilities capable of producing 10 tons of Window per month by July, 1943, and to have 10 tons on hand by that date for experimental purposes. At that time RRL had only one cutter on hand, and there were doubts as to the length of time it could remain in satisfactory operation. However, by constructing cutters on a rush basis both in the Laboratory's machine shop, and at a manufacturing plant in Nashua, N. H., the necessary number of Window cutters was delivered on time, and production was begun. In this way, United States production was ready when the British used Window during the first raid on Hamburg, Germany, in August, 1943.

The Window used by the British on this raid weighed nearly two pounds per unit. The British had heard, through liaison channels, of U. S. work on Window and of the success obtained by narrowing down the width of the strips. The strips used in the Hamburg raid were narrower than any which the British had employed before, but were still far less efficient than the U. S. Window. Because of their immediate needs, the British were allocated half the Signal Corps Window machines, which were sent to England with the understanding that the Window produced there would later be available to both the AAF and the RAF. The British bought 150 additional machines on orders through Treasury Department Procurement. As it worked out, the AAF later obtained a good deal of Window from the British. Thus the original effort expended in helping the British build up their Window production, repaid itself.

When Window was first placed in operational use by the U. S. AAF, in October, 1943, the U. S. production Window available to our Air Forces weighed three ounces per package as compared to 27 ounces for the British equivalent. This difference meant not only a tremendous economy in material, but also the possibility of carrying a greater bomb load in view of the saving in weight.

From that time on, the research problem consisted of effecting further refinements and improvements in Window design. Development of a suitable package was in itself no mean task - the bundles had to be designed to open at various air-speeds after just the right delay to release their contents intact.

In view of the shortage of paper backing, and of the shortage of manufacturing facilities for gluing paper backing to metal foil, cutters were improved sufficiently to make possible the manufacture of Window made of pure metal foil. In addition to the saving in weight, this foil had another important advantage - its percentage dispersal was much greater than the older paper-backed variety.

In view of the high security which required that all Window tests in the early days be conducted over water so that none of the material might fall into unauthorized hands, little was known as to the percentage of strips in each Window bundle which actually dispersed in the air and thus became effective as radar reflectors. When tests over land were finally permitted, it was discovered that a sizable per-

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centage of the strips became entangled after release and fell as a solid mass, or "bird's nest", thus contributing little to the echo produced. As soon as this effect had been discovered, steps were taken to increase the amount of dispersal. It was found that the pure foil Window gave a remarkable high percentage dispersal - so high, in fact, that the problem was no longer serious if the Window were dispensed from chutes properly designed and located in the aircraft. (Window ejected from improperly designed or placed chutes often suffered damage on emerging into the slipstream)

Subsequent improvements included a so-called "triple unit" consisting of three single units of Chaff, each of differing lengths, contained in a single package. Capable of giving response over a wide frequency band, this "triple unit" was an answer to the growing spread of the Wurzburg frequency band, and weighed less than 2 ounces per unit.

U. S. aluminum foil production was increased approximately three times during the war. Nearly 75 per cent of this total production was devoted to Window.

Shortly after the development of a satisfactory Window bundle, studies were made of possible means of automatically ejecting a large number of them from airplanes. Early attempts involving containers of fixed size proved impractical in view of the difficulty of predicting the amount and shape of the space available in aircraft for installations of this sort. The most practical design proved to be one which used bundles of Window each glued crosswise on long tapes. As these tapes were drawn through rollers, the Window bundles were automatically torn off and ejected. The advantage of this scheme lay in that the taped Chaff could be stored in one or more cardboard cartons easily stowed in the plane, from which the bundles were pulled by the tapes as required.

Window dispensers proved to be entirely practicable for heavy and medium bombers. In the case of fighters, however, space was seldom available for an internal installation of a Window dispenser. To meet this need, RRL developed a Window dispenser and Window storage container mounted in a streamlined container similar in shape to a bomb or an expendable gas tank. These "Window" Bombs would undoubtedly have seen wide use had the war continued.

The low-frequency radars used by the Japanese required a Window technique different from that employed in the European theater. In the 100 to 200 megacycle range, Chaff bundles become long and bulky and difficult to handle. This led to the development of a type of radar reflector, known as "Rope", which consisted of 400-foot rolls of thin aluminum tape, half an inch wide. When rolled up, the tape formed a roll 2 3/4 inches in diameter. One end of the roll was anchored to a small paper parachute, or a piece of cardboard, so that when ejected from a plane, the tape would unroll itself very rapidly into a long streamer. By making this streamer fall in such a way that it assumed more or less random orientations, instead of being exactly vertical, the "Rope" proved to be extremely effective against radars of any polarization. Rope has the further advantage that it will operate over a wide frequency range. "Rope" was used extensively in the Pacific theater by B-29's and other heavy strategic bombers.

Transmitters

In the design of jamming transmitters, the first and most important technical problem faced by the Laboratory was to discover how much power was needed to jam various kinds of radar sets under various conditions. It was not known, for

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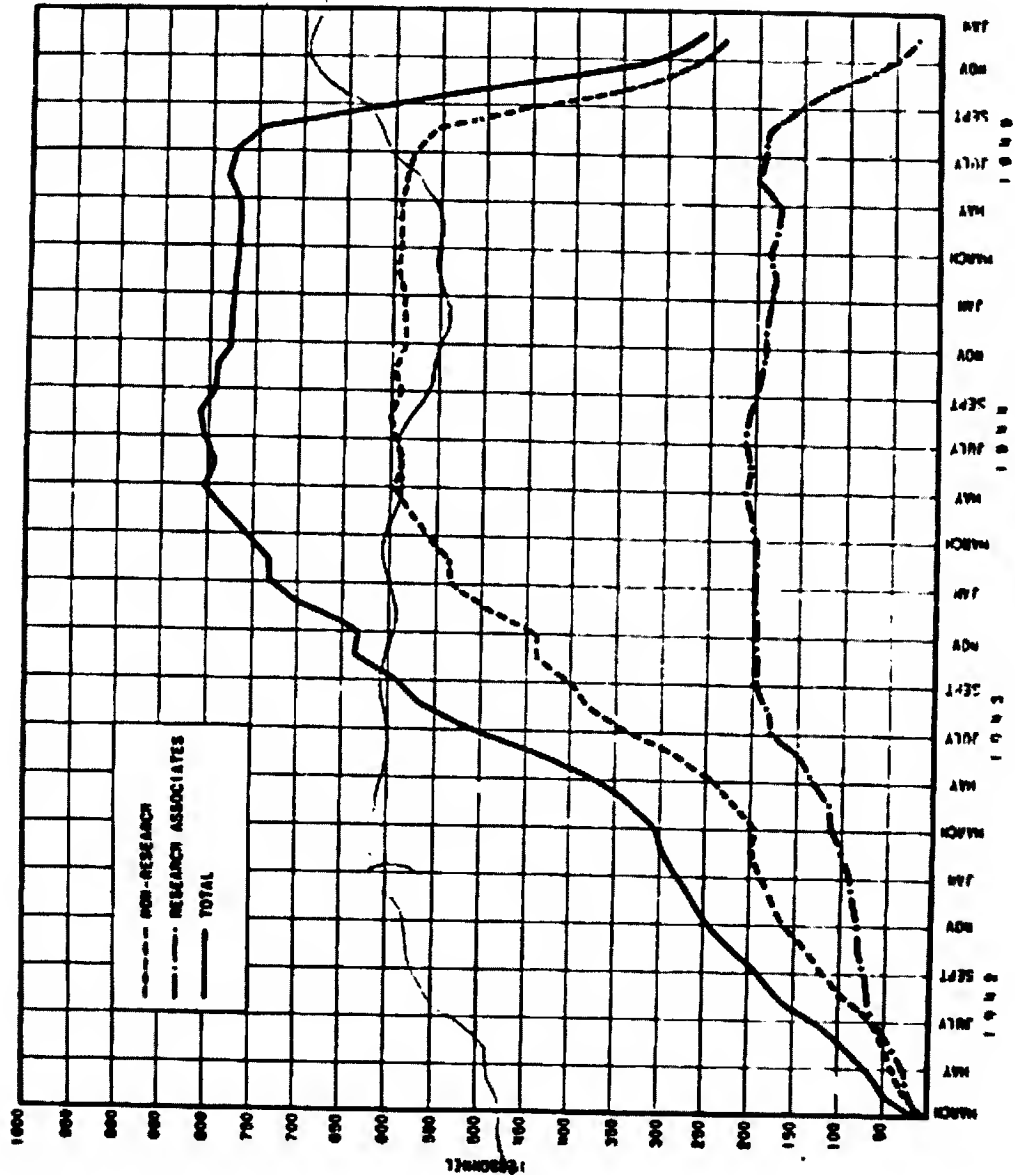


Figure 10. Growth of the Pacific Research Laboratory

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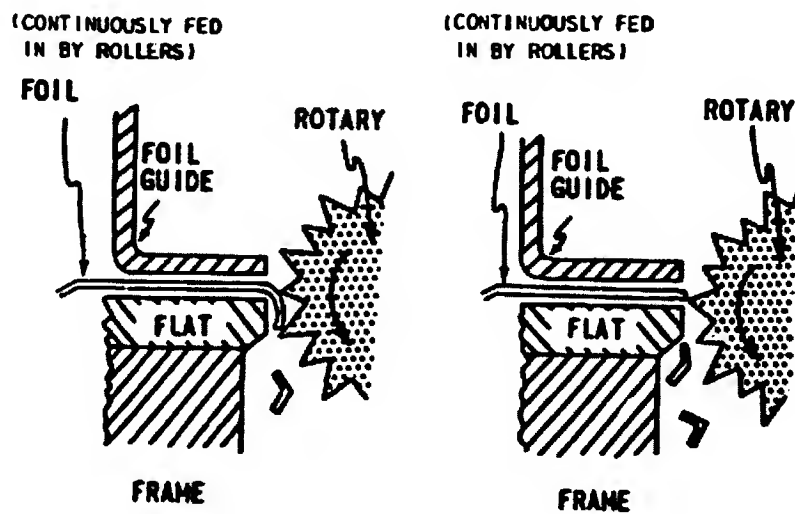


Figure 21. How the Window cutter operates

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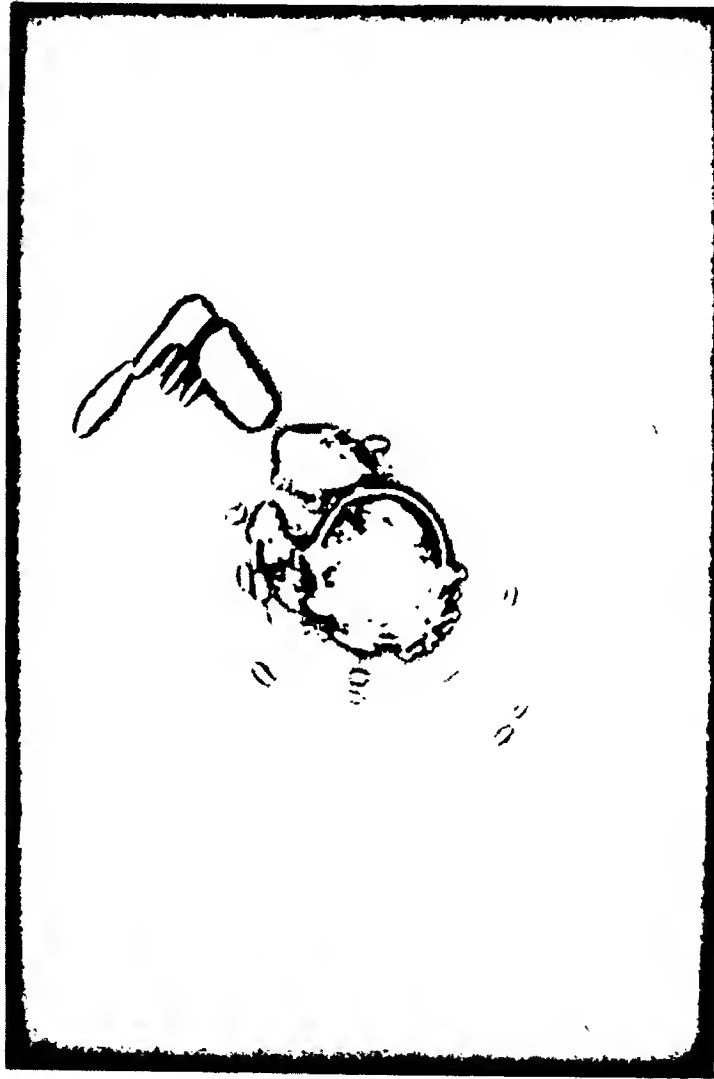


Figure 22. The L-shaped patch on the PPI at 7 o'clock is Window; planes are visible inside apex of "L"

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411-299



Figure 23. A common sight in Germany: Bird's nest beside an autobahn

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411-299

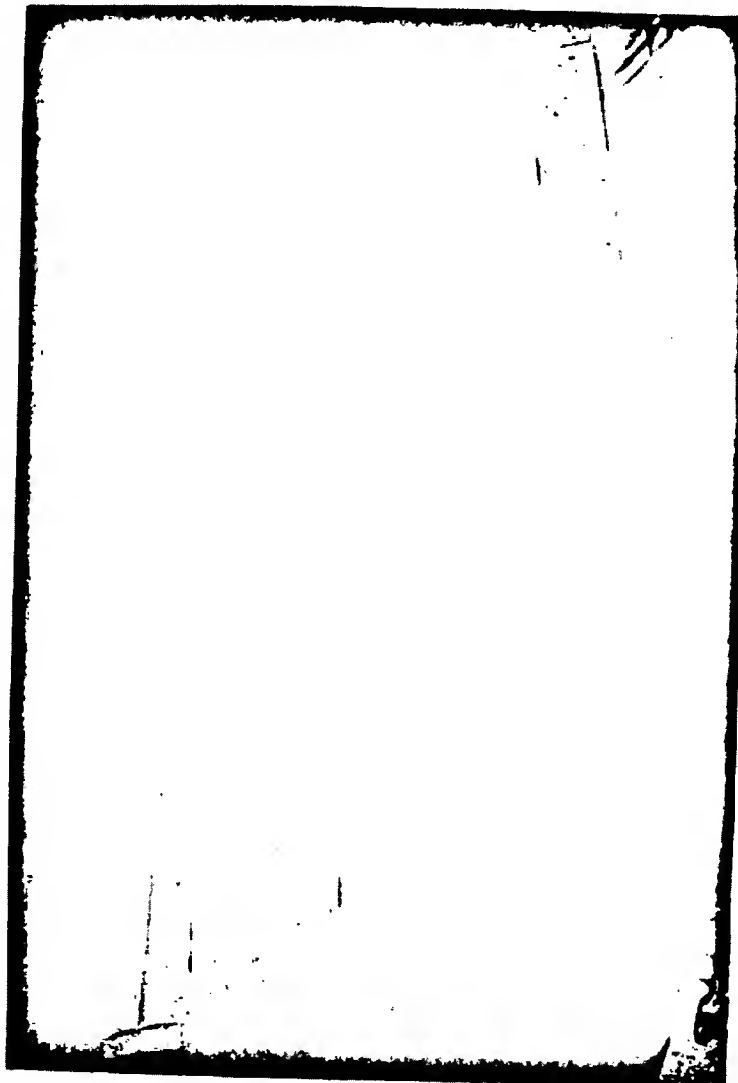
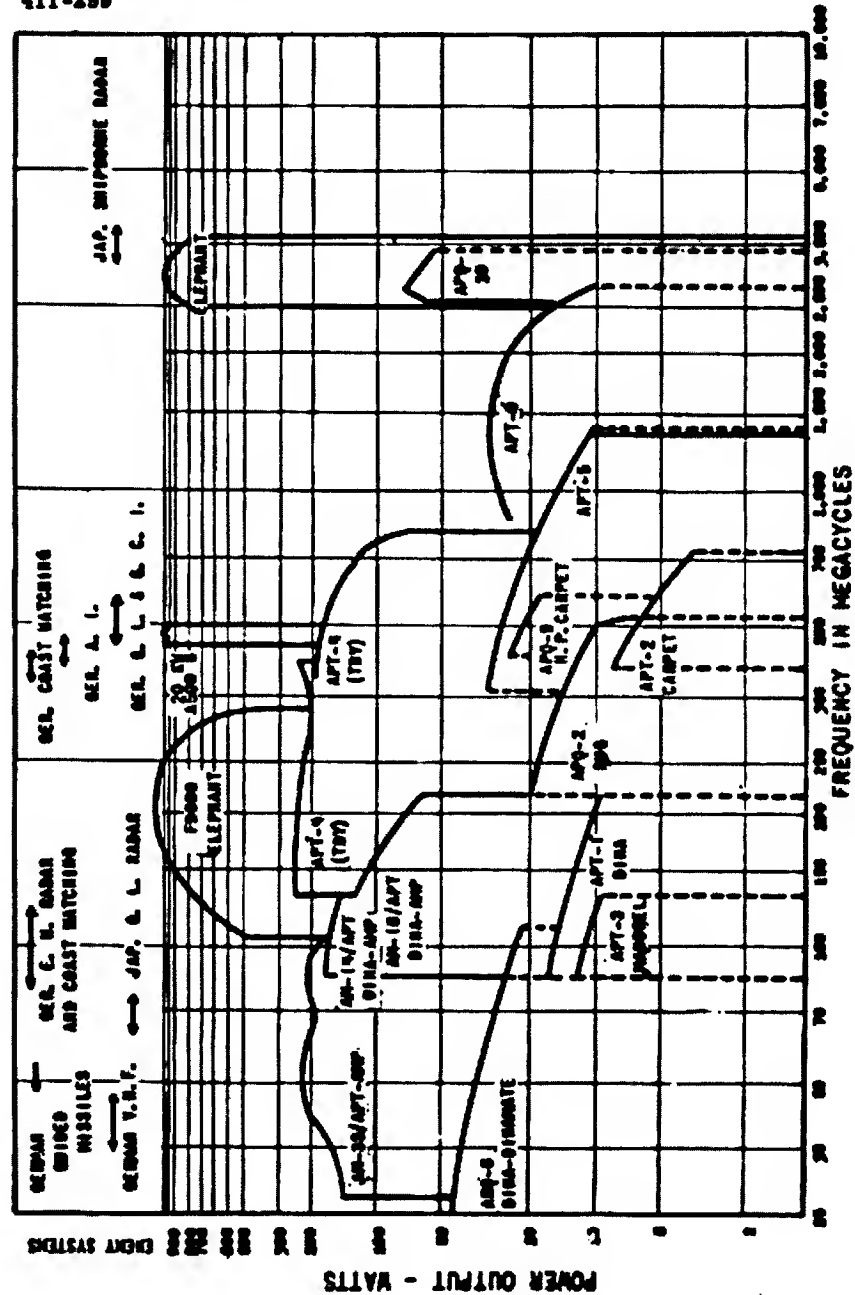


Figure 24. Taped all-metal Chaff; RR-4/U

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411-299



RRL JAMMING TRANSMITTERS IN PROCUREMENT
Figure 24A.

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example, whether the power requirements for an airborne jammer would turn out to be of the order of 5 watts or 50 watts. If it had turned out to be the latter, it is likely that the Laboratory would never have developed to the extent that it did.

Since it was by no means clear, at first, what sort of jamming modulation should be used, the choice of noise modulation for the jamming signal was an important decision. This had been proposed by Telecommunications Research Establishment, although the only British jammers actually in use at the time employed high-frequency sine-wave modulation. Noise proved to be the correct decision. Although other simpler forms of modulation were from time to time proposed, even up to the very end of the war, none of these alternative forms was ever used operationally by our forces except in very special cases.

One of the earliest activities of the Laboratory was to build an artificial radar system on which to study the appearance and the effects of the various forms of jamming. Later on, more extensive studies were made of such combinations as noise amplitude modulation plus a certain amount of frequency modulation, etc. The results all pointed to the fact that noise amplitude modulation or amplified noise itself was the most effective type of signal.

It was RRL's policy to take ideas which seemed to be good ones, wherever they could be found. Starting, so to speak, from scratch, the Laboratory had few preconceived notions which might serve to limit or restrict thinking.

Once the optimum type of modulation had been found - and it is significant that the first RRL report to be published (RRL #1, dated July 8, 1942) treated a new and more effective source of noise jamming - the next problem consisted of finding out what sort of jamming equipment could be carried in Service aircraft. It was not known for example, how much additional weight or how much additional power drain could be tolerated. As a result of considerable liaison work and consultation with the Services, it was found that an equipment approximately one Standard Aircraft Rack in size, weighing 40 or 50 pounds, and drawing three to four hundred watts of power, would probably be acceptable. The first RRL jammers, therefore, represented attempts to build as much power output as possible into a space of that given size.

The Laboratory's early low-frequency jamming transmitters - Mandrel and various modifications thereof - were built chiefly for test purposes in order to try out the idea of jamming on the most readily available U. S. radars. The first higher frequency development - Carpet - was based on a probable British need and again was intended to show the possibilities of constructing equipment for that general type of application.

The Laboratory's basic philosophy was to make a transmitter as powerful as possible within the limits of the assigned space and weight. In order to cover the various frequency ranges in which enemy radars might appear, it was necessary to build a line of jamming transmitters with power outputs of the order of 5 to 20 watts, each occupying 1 to 1 1/2 standard aircraft racks, as shown on the attached chart.

As the program developed, however, the necessity for designing higher powered transmitters became apparent. Moreover, as RCM began to be accepted by the Services, there was a willingness and even a desire to carry more pounds of RCM gear. When new tubes became available, higher power transmitters such as the AN/APT-4 were made possible. The increased power naturally made necessary

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411-299

an increase in the size and weight of the equipments. However, the AN/APT-4 magnetron transmitter (which weighed 190 pounds, and drew 1500 watts of power) proved practicable and would undoubtedly have been introduced on a fair scale had the war continued much longer.

Developments of transmitters for higher and higher frequencies called for the use of new tubes and new techniques. Experiments showed that the new, high-power lighthouse tubes, when used with cavity resonant circuits, were capable of high output over a wide frequency range. This discovery led to the AN/APT-5 and AN/APT-9 transmitters, of which the latter is capable of operation from 300-2500 megacycles. There is no doubt that the development of these tubes was considerably speeded by their application to RCM problems.

An interesting development was the APT-1 or "Dina" transmitter, which was really intended to be an improved Mandrel. In this design, an entirely different approach to the problem was used, which made possible the realization of a higher power output for a given total input - at the same time with a type of jamming signal which was more effective than any used before.

A separate Laboratory group was set up for the study of noise sources in an effort to improve on the photo-multiplier tube. As a result of the work of this group, a new and even better noise source using a gas tube was discovered.

Concurrently with the development of a line of relatively low power airborne jamming transmitters, another countermeasures problem came up, namely that of providing a lane in which British bombers, returning from raids over Germany, would be safe from attack by night fighters. In order to do this, enormous jamming powers were required, and the British became interested in a U. S. tube development which had been in progress since the early days of the war. This tube, known as the resnatron, had been originated at the University of California; it gave promise of power outputs far in excess of any previously achieved. Westinghouse was given a contract for the necessary tube development, and RRL undertook to incorporate these tubes in a practical jamming system.

It so worked out, that at a time when the best attainable jamming transmitters using conventional tubes were producing some 20 watts of energy, the resnatron equipment, known as "Tuba", was producing powers of the order of 1000 times this amount.

This remarkable result was not achieved without a tremendous technical effort. The high powers involved made necessary the development of many new techniques; for example, monster waveguide "plumbing", including switchgear and dummy loads capable of dissipating large amounts of power had to be developed. In addition to the complications introduced by the necessity for water-cooled seals, etc., the resnatrons had to be made tunable over a relatively wide frequency range and yet free from all parasitics. Provision for wide band modulation was also required. All of these considerations would normally be considered incompatible with high power operation! Yet Tuba incorporated them all, with an efficiency of operation which varied between 40 and 80 percent. The maximum power output obtained (for a test of short duration) was 87 kilowatts.

As a result of the experience with Tuba, the possibility of achieving really high power jamming systems became apparent. Tuba opened up new frontiers of continuous-wave power at high frequencies, and although it did not see much operational use as a result of a change in the tactical situation, it gave rise to other

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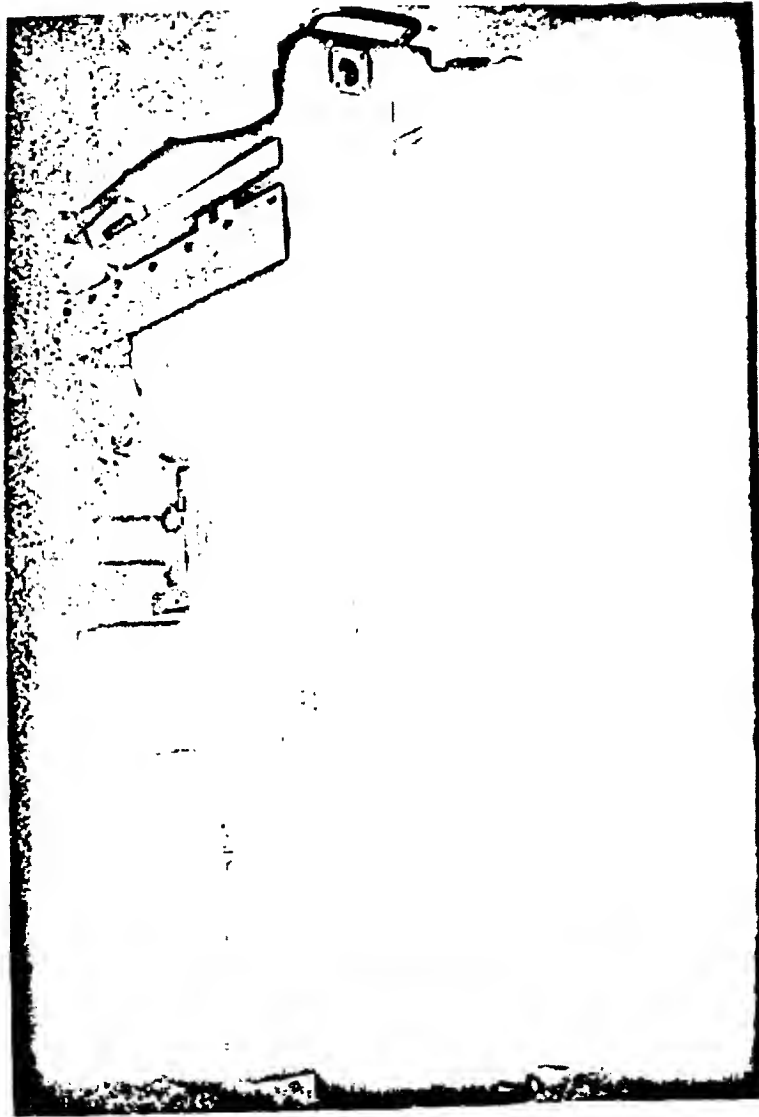


Figure 25. 200 pound, 150 watt airborne magnetron jammer-AN/APT-4

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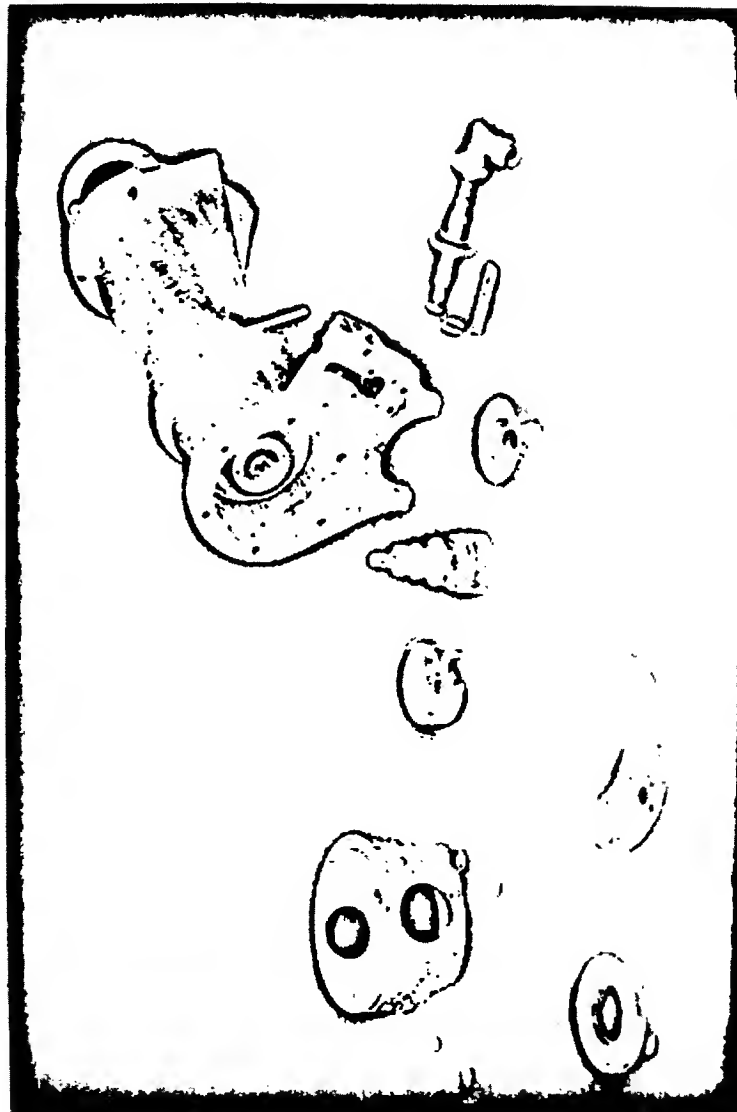


Figure 26. Exploded view of the AN/APT-9 lighthouse tube oscillator

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Figure 26A. Artist's conception of the production Tuba equipment
as set up in England

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important developments. Moreover, Tuba should have important post-war applications.

Not long after real results had been achieved with the resnatron, experiments showed that the power required to conceal ship targets from radar observation was far greater than that required for the equivalent airborne case.

As a result, it became apparent that the low-power airborne jammers used on ships and landing craft in the early days of the war would not be enough to do a satisfactory job at close ranges. This realization increased the priority on high power jamming transmitter developments, and eventually led to a one-kilowatt shipborne jammer known as "Elephant". This high power jammer was made possible by the development of a satisfactory tunable 10 centimeter, continuous wave magnetron - a development which would have been considered impossible before Tuba lifted the horizons.

An intermediate development in this chain was the shipboard equivalent of the airborne 150 watt jammer - the TDY. RRL experience in designing a Laboratory prototype of the shipboard jammer was of great assistance to the Navy during the development of the TDY equipment, which became standard aboard Navy ships of destroyer-size on up.

Receivers

The first step in any countermeasures program involves listening for enemy radar signals. At the time the RRL was organized the only equipment available for this service was a search receiver equipped with two tuning units for the frequency ranges 100-300 Mc and 300-1000 Mc.

These original tuning units had two tuning adjustments - one for the oscillator, and one for the antenna input, with the result that they were awkward to use in actual practice and had many spurious responses which were often very difficult of interpretation. Single dial tuning units for these receivers would make a big difference in their effectiveness. RRL undertook mechanically to link the two controls together, in order that tuning could be carried out as in an ordinary home receiver. Concurrently with the development of improved tuning units, the development of two additional frequency ranges was undertaken: one covering 30-100 Mc and the other covering 1000-3000 Mc.

Since the production of the original receiver had been limited, and since various refinements in design were possible, two completely new sets using the improved tuning units were developed.

These two receivers, known as the APR-1 and APR-4, went into large procurements by the Navy and the Army Air Forces respectively. The two equipments were nearly alike; the chief difference being that the APR-4 was provided with a choice of bandwidths.

It was realized at the outset that the frequency ranges 1000-3000 and 3000-6000 Mc required a new approach in receiver design. Proposals for new tuning units for the APR-1 and APR-4 type receivers had all involved use of a harmonic of the local oscillator for conversion; this arrangement, while practicable, made interpretation of results more difficult in view of the increased number of possible spurious responses. The first step, therefore, consisted of developing a local oscillator capable of tuning over a high enough range of frequencies. The most

satisfactory design used a lighthouse tube in a coaxial circuit. It tuned from 1000-3000 Mc on the fundamental, and 3000-6000 Mc on the second harmonic. A microwave intercept receiver, known as the AN/APR-5, was accordingly built around this oscillator. With slight modification, this receiver became the Navy's AN/SPR-2. Both receivers were manufactured and used in quantity by the Services. Moreover, these superheterodynes were used in preference to simpler "interim"-type receivers employing direct detection, such as the "Spud" or "Zero Catcher".

It was realized from the start that the receiving operator would not always be able to devote full attention to his equipment. On long missions, the effect of fatigue becomes extremely important. With this in mind, the Laboratory endeavored always to design equipment which would be simple and easy to operate. This foresight was amply repaid in the case of operations carried out by B-29 aircraft, many of which flew missions for fifteen hours or more. An important adjunct to any search receiver is an automatic recorder, which makes it unnecessary for an operator to pay continuous attention to his receiver.

One of the earliest Laboratory developments was a receiver known as the "Autosearch", which incorporated such a recorder. This receiver was intended only to provide a preliminary indication of the existence of radar signals and their approximate frequencies, and was never used widely because it was supplanted by the more accurate superheterodyne receivers before quantity production got under way. Moreover, the superheterodyne search receivers could do the same job when fitted with a special tape recording attachment known as the APA-41. This device, coupled to the tuning control, made a continuous record of the signals received during each frequency scan; it could easily be disconnected if a more detailed study of a particular signal were desired.

Satisfactory pulse analyzing and panoramic display equipment had been developed before the RRL came into existence. Yet most of the panoramic adapters weighed a good deal and were packed in large, ungainly cases which occupied more space than was necessary. RRL devised, for use in connection with its radar jamming systems, a half-SAR radar panoramic adapter which came to be known as "Panda". Simple both mechanically and electrically, this device proved eminently satisfactory for use with the standard search receivers, and made possible a considerable saving in weight and space.

In the early days of the countermeasures program, when the eventual trend was by no means clear, work was done at the RRL on a species of warning receiver widely used by the British to give their bombers indication of the approach of night fighters and, in some instances, indication of their observation by German ground radar, particularly GCI sets. Experiments with direct detection-warning receivers of various kinds, some of them narrow-band and some of them relatively wide-band, showed that they had considerable possibilities for the application intended. However, the tactical requirements of the U. S. AAF never called for the widespread use of devices of this sort: flak constituted their chief problem, since the majority of their raids were carried out in daylight in the company of fighter escort.

Whereas simple jammers and receivers would serve satisfactorily at the lower frequencies, it was found that as the higher radar frequencies were approached, particularly at 3000 Mc and above, the technical requirements on a jamming system were very considerably increased. It is much more difficult, for example, to keep a jammer on frequency in the S-band, in view of the greater tendency for both radar and jammer to drift enough to put most of the jamming signal outside the

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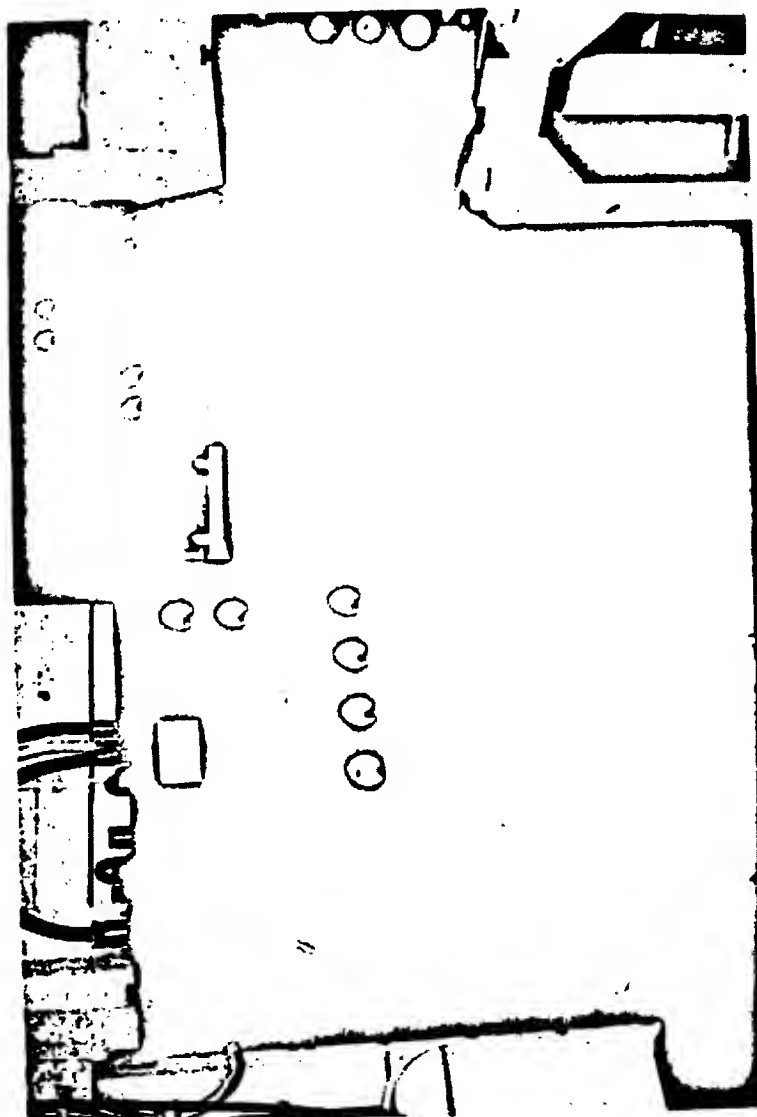


Figure 27. 150 watt TDY jammer at the left; one kilowatt Elephant transmitter console at right

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radar receiver acceptance band. Moreover, the difficulty of carrying out barrage jamming at the higher frequencies made it desirable to design transmitters for spot jamming use only - that is, for relatively narrow band operation. As a consequence, RRL jammers for the 1000-2500 Mc range (AN/APQ-21) as well as for the 2000-4000 Mc range (AN/APQ-27) were designed insofar as possible to function as integrated systems consisting of transmitter, receiver, pulse analyzer and frequency-setting equipment.

The culmination of this trend is represented by the "Elephant" development. In early 1945, this one-kilowatt, 10-centimeter equipment incorporated the latest ideas on the design of jamming systems. It was provided with two complete receiving sets, one of which was used for searching, while the other was used for setting the jammer and maintaining it on the proper frequency. The receiver used for searching was arranged to scan a relatively wide section of a total spectrum, and to present the output information gained on a panoramic display oscilloscope. As soon as a receiver was switched over to spot-jamming, the bandwidth of the scan was considerably reduced so that a more accurate display would be available to set the jammer on the desired channel.

Antennas

Since radar countermeasures transmitters must be capable of operating at whatever frequencies may be selected by the enemy, the antennas to go with these transmitters should preferably operate over as wide a range of frequencies as possible. In this way, the operating frequency may be changed without returning the antenna or switching over to a new one.

In the early days of the Laboratory, this problem was clearly recognized, and a program of designing and developing countermeasures antennas of as large a bandwidth as possible was begun. However, for the sake of speed, the Services went ahead with the procurement of certain interim RCM antennas which, because of their narrow bandwidth, had to be cut to the frequency at which the associated transmitter was to be used.

Prior to the war, there had been little reason to develop antennas for wide-band operation. The requirements of television, radar and multi-channel VHF were all satisfied by radiators capable of operating over a 10 per cent frequency range. Yet some of the designs worked out for these three applications proved to be useful in the case of RCM. Low frequency countermeasures transmitters were used with the thick sword-type stubs originally designed for use with VHF in the 100 Mc frequency range. From television came the cone antenna design widely used for RCM receivers. RRL did much basic research work into the bandwidth achievable with this type of antenna.

After considerable liaison work and study of current practice, RRL adopted a 50 ohm impedance as the standard for antenna feed cables. For transmitters, a 2-to-1 voltage standing wave ratio (abbreviated VSWR) at the antenna was considered the maximum allowable mismatch for proper operation. In the case of receiving antennas, however, a maximum VSWR of 5 to 1 was allowed.

The Laboratory developed cone receiving and transmitting antennas capable of a 3 to 1 frequency ratio - from 300 to 1000 Mc. Further research showed that this excellent performance could be bettered by careful attention to the design of the taper between the transmission line and the antenna feed point. A similar re-

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ceiving antenna was then produced, which would operate over the phenomenally large frequency range from 300 to 3000 Mc - a 10 to 1 frequency ratio.

Most of the early RCM antennas were designed to be one-quarter wavelength long at their lowest frequency of operation, and were consequently used with ground screens or surfaces. This came about both because the first application of countermeasures equipment was in aircraft, and because early intelligence information indicated that the majority, if not all, of the German radars were vertically polarized. In order to jam an early-warning set in the 100 Mc frequency range, it is only necessary to mount a quarter-wave stub on the bottom of the aircraft so that it projects straight down.

In the case of ships, however, the problem was somewhat different. In the first place, ships do not have conveniently located surfaces which might be used for ground planes. In order to give a more or less non-directional receiving pattern, dipole antennas had to be used. These dipoles were made up of thickened stubs and cone antennas operated back to back, and while the coverage was not perfect, they were suitable as interim devices.

When it was found that the size of ship targets made much greater jamming powers necessary, it was apparent that some directivity and hence power gain, should be provided by the antenna system itself, in view of the difficulty of obtaining sufficient RF energy at radar frequencies. Yet the transmitting beam could not be too sharp in a vertical direction, because motion of the ship might tilt it above or below the target. A design was arrived at which was eventually used very widely by the Navy. It consisted of a series of corner-reflector-type directional antennas on rotatable mounts. The direction in which the mount and consequently the antennas pointed could be remotely controlled from the countermeasures room. A wide frequency range was covered by mounting two or more antennas (some back to back) on the same mount. Still further extension of the operating range could be accomplished by removing the dipole assembly at each corner reflector, and substituting a different one.

The dipole elements used in these corner reflector type antennas were of the "sieve" type. While this design did not provide as wide a frequency coverage as the thick cones, it was much more compact and more readily mounted in a practical transmitting system. RRL greatly extended the possibilities of the sleeve antenna design which had been used only to a slight extent for television work before the war.

Protection of aircraft from enemy gun-laying radar requires that the antenna direct the majority of the transmitted energy downward and slightly in front of the aircraft. The most desirable antenna pattern is one which follows a cosecant-squared law, so that the jamming energy received by a radar on the ground increases as the plane approaches, in exactly the same amount as the echo returned to the radar from the plane. In this way, a constant jam-to-signal ratio is maintained and the jammer power is used as economically as possible.

The German gun-laying radars introduced an additional problem as well. Although the early Wurzburgs did not have them, later models were equipped with transmitting dipoles which were slightly offset from the center of the parabolic antenna and rapidly rotated in order to obtain a rotating directivity pattern for lobe-switching. Since the radar antenna rotates, the polarization of the signal received at a target is constantly changing through 360 degrees at the lobe-switching rate. If plane polarized jamming (such as that obtained from the early Carpet

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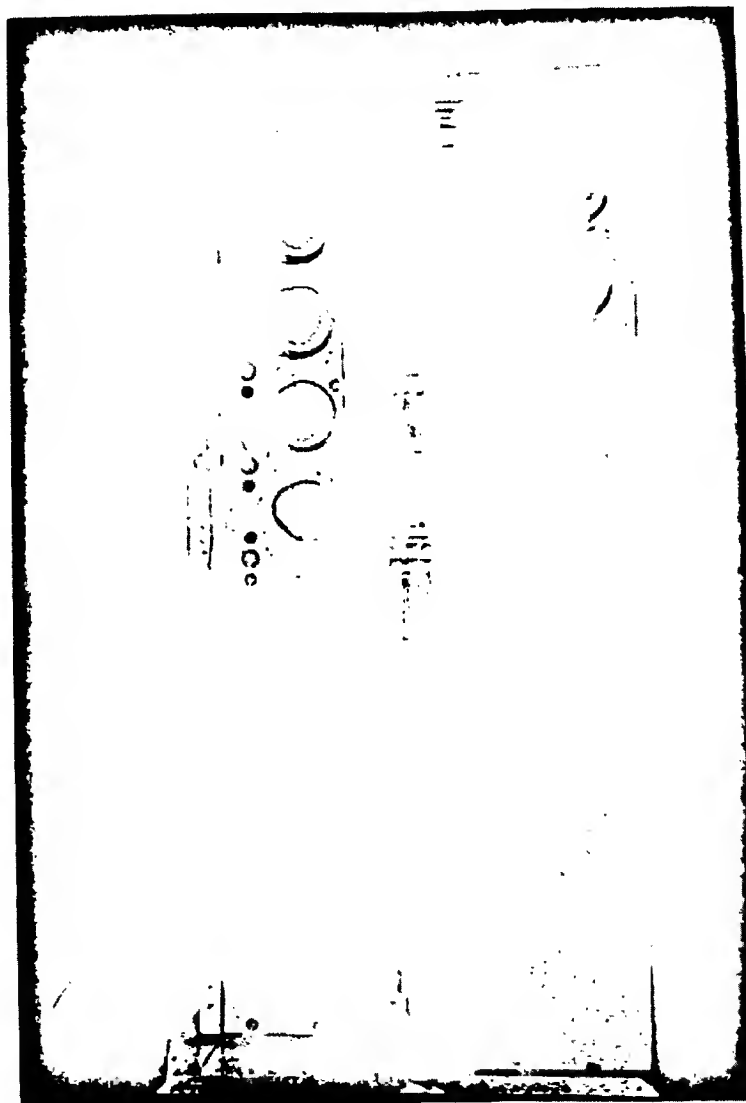


Figure 28. AN/APR-5 microwave intercept receiver.
1000-3000 Mc lighthouse tube oscillator in center

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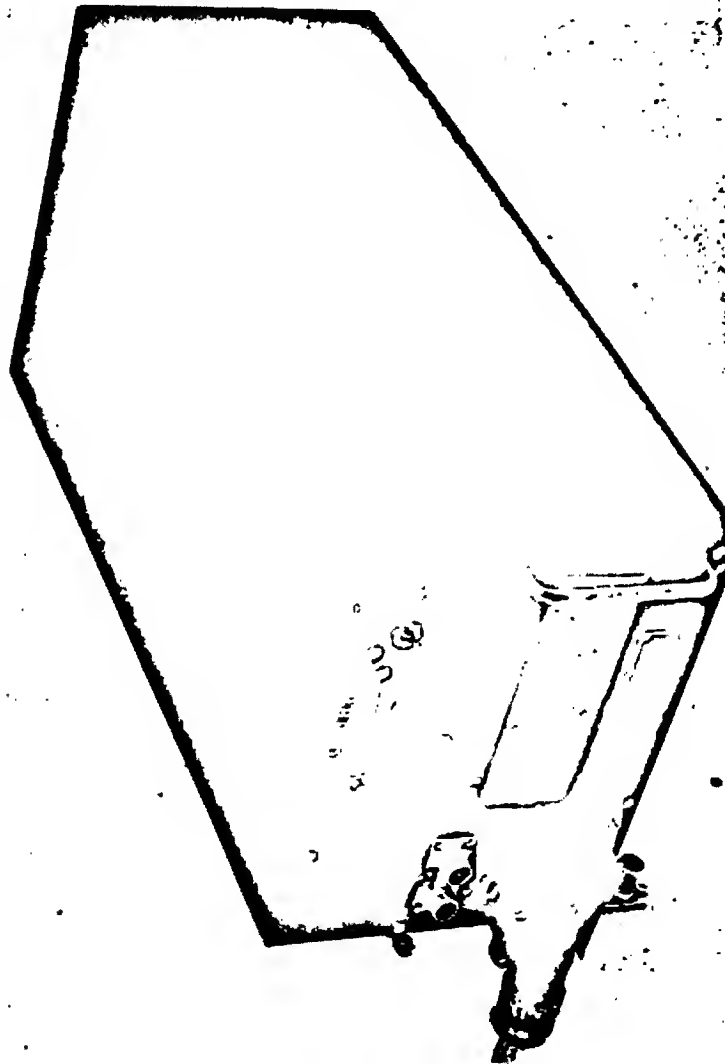


Figure 29. AN/APA-23 recorder for search receivers

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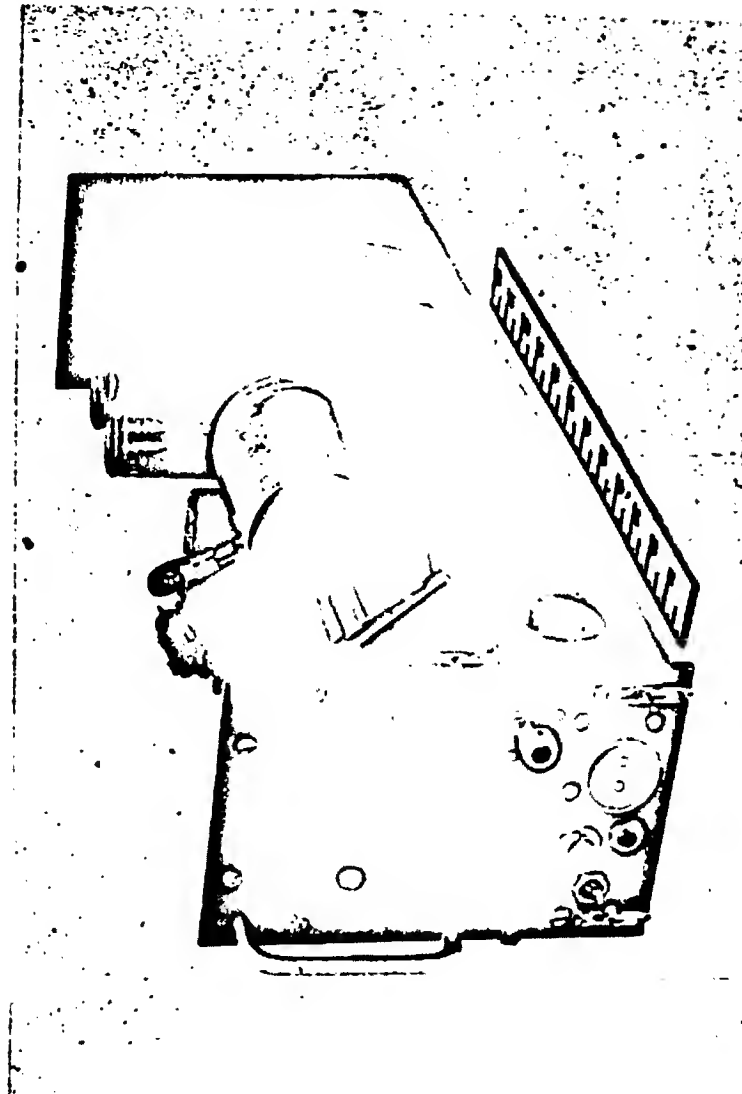


Figure 30. AN/APQ-27 microwave spot jamming system installation

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transmitters) is used against such a radar, the jamming will not be complete, since the radar cannot pick up the jamming signal when the radar's antenna is oriented at right angles to the jammer antenna.

This possibility was recognized by RRL as soon as the German use of rotating dipoles was definitely established, and a jammer antenna was devised which could jam the Wurzburg no matter what the angular position of its dipole. Thus, by the time the Germans took advantage of the plane-polarized jamming and devised a blanking circuit which permitted their radars to "see" only during those instants when the two antennas were at right angles, the U. S. AAF were ready with the answer - a rotating field antenna popularly known as the fishhook. The design, production and installation effort the Germans put into their anti-jamming device, was thus completely nullified. In addition, the fishhook (AS-69/APT) provided the cosecant squared antenna pattern desired for use against gun-laying radar. Fishhooks were supplied as standard equipment with the volume shipments of Carpet transmitters sent to the European theater.

The Pacific countermeasures problem differed from the European one in that relatively low frequency radars were used, - radars whose polarization was predominantly horizontal. To achieve a downward-looking pattern, the Fishhook type design was impractical in view of the size of the antenna elements at those frequencies. Yet it was necessary to enable an aircraft to transmit a horizontally polarized jamming signal which had a rough maximum in the forward direction and which gave coverage all around the horizon. This problem was solved by mounting two horizontal quarter-wave stub antennas - bent backward at an angle of 45 deg. - on either side of the airplane's fuselage. When fed out of phase, these two antennas functioned in much the same manner as a dipole, giving a horizontally polarized signal which was strong in the forward direction. The backward rake of the antennas filled in the nulls off the sides of the plane, giving a horizontally polarized coverage pattern which was remarkably complete. The technical problem involved in feeding the two antennas out of phase was solved by means of a balance-to-unbalance transformer called the "Bazooka". In its original form essentially a single frequency device, the Bazooka was redesigned to give satisfactory balance over a frequency range commensurate with that covered by the antennas themselves.

Later on in the war, high speed aircraft received a very considerable amount of attention from the Services. Jet-assisted bombers and fighters, operating at speeds many times those of the slower B-17's and B-24's, required special attention in the design of radio antennas. Even small projections from the smooth skin of these aircraft could give rise to very considerable drags and reductions in speed. Ordinary radio antennas were said to cause a very considerable reduction in the maximum speed even in the case of B-29 aircraft.

This problem was attacked at RRL in two general ways. It was found that by increasing the "finess ratio" of stub antennas (that is, the ratio of width to thickness) the drag could be very considerably reduced. Moreover, "slot-type" antennas were developed which gave satisfactory radiation patterns over a remarkably wide band of frequencies without requiring any projection outside the skin of the aircraft whatever.

Very remarkable developments made possible the realization of satisfactory jamming antennas for use at microwave frequencies. Circular polarization was desirable, since many microwave radars have spinning dipole antennas. At the same time, operation over a wide frequency range was desirable, provided that the shape of the antenna pattern and the circularity of polarization did not change

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too seriously in the process. Any one of these requirements alone would have been difficult to meet by means of pre-war techniques - yet all were actually satisfied in one design, a horn-type antenna used with the APQ-27 and other microwave systems. The M2903 horn is capable of operation over a 2 to 1 frequency range with approximately constant feedpoint impedance, circularity of polarization, and antenna pattern.

Direction Finders

Radar equipments, like all radio stations, can be located by means of direction finders. However, when RRL first began work on radar direction finders, it was not at all clear how they would be used in actual operational practice. This was purely apart from the technical problems inherent in their design which were not inconsiderable since the highest frequencies at which radio direction finders had been made to operate successfully before the war was of the order of 120 Mc. It was necessary in working out the equipment to do the job, to envision at the same time the military tactic or situation in which the equipment would eventually have to be used. Since neither the Armed Forces nor the civilian researchers had had much experience with problems of this sort, the fact that they were worked out to everyone's satisfaction in the end is another important result of the close cooperation which existed between the Services and RRL staff members.

As might be expected, airplanes and ships proved to be the best vehicles for radar direction finders. In the case of aircraft, two general types of operations involving direction finders proved to be the most common, and these called for the development of two different kinds of direction finding equipment.

If it is desired to proceed directly to a radar in order to destroy it, homing equipment will suffice. Simpler in design because only a fixed antenna is used, homing equipment was employed in the Pacific theater by 13th Air Force B-25's which hunted down isolated Japanese early warning radars and destroyed them by gun- and rocket-fire. A satisfactory homing system for use in fighter planes, known as AN/APA-48, was crash-produced for use by U. S. carrier aircraft. This equipment, which was being placed in service when the war ended, was to have been used to locate Japanese radar-equipped "snooper" planes which had a habit of tracking our task forces from a distance just outside the range of U. S. ship radars.

However, homing technique is impractical when the intention is simply to locate a radar. Direction finders with movable antennas make it possible for planes to plot the location of a radar from data taken while the plane flies a known course in its vicinity. Direction finders of this type, widely used by radar-hunting Ferret planes, were also carried on bombing aircraft and successfully used to locate radars during regular bombing strikes. The technique was especially useful in the case of long B-29 missions where detailed ferreting on the part of a single aircraft would have been impractical.

Satisfactory direction finders were developed at RRL for all the commonly used radar frequency ranges. A simple system - known as the AN/APA-24 - using dipole-type antenna elements, was developed for the lower frequencies. Provided with a series of plug-in interchangeable heads, the AN/APA-24 covered from 70 to 400 megacycles. Capable of good results at the lower frequencies, the APA-24 was nevertheless compact enough to permit mounting on high speed aircraft like the B-29's. Although a null-type device, the APA-24 was nevertheless

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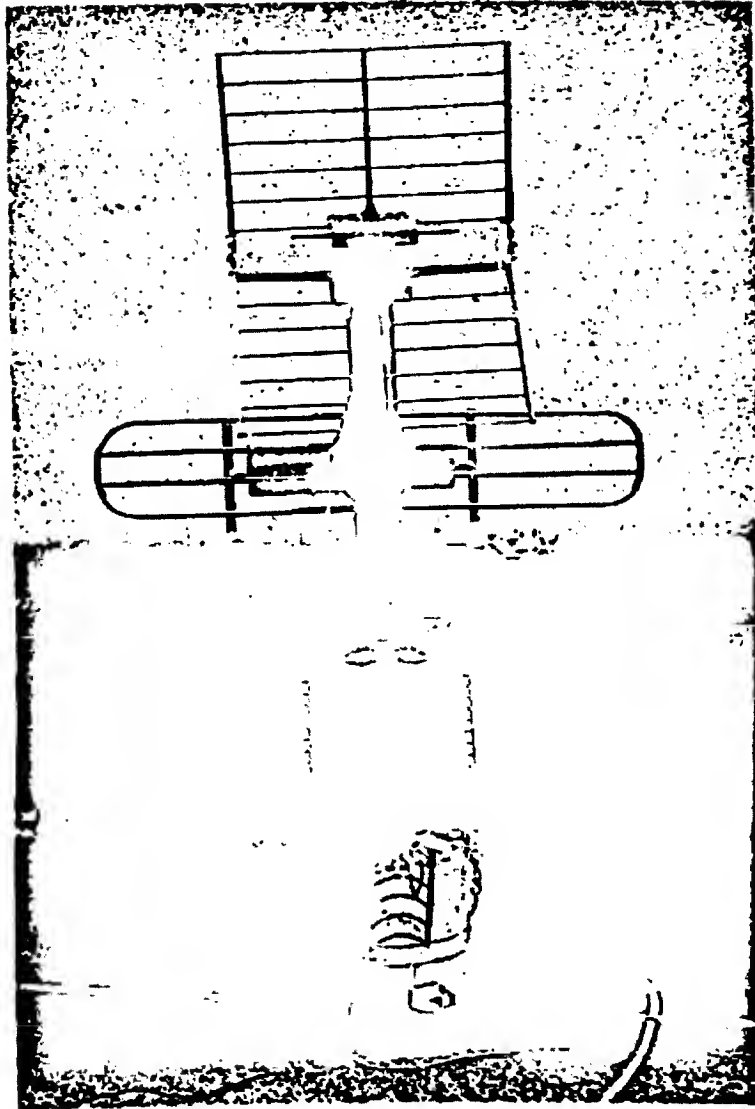


Figure 31. Rotatable directional antenna used with ship-borne TDY jammer

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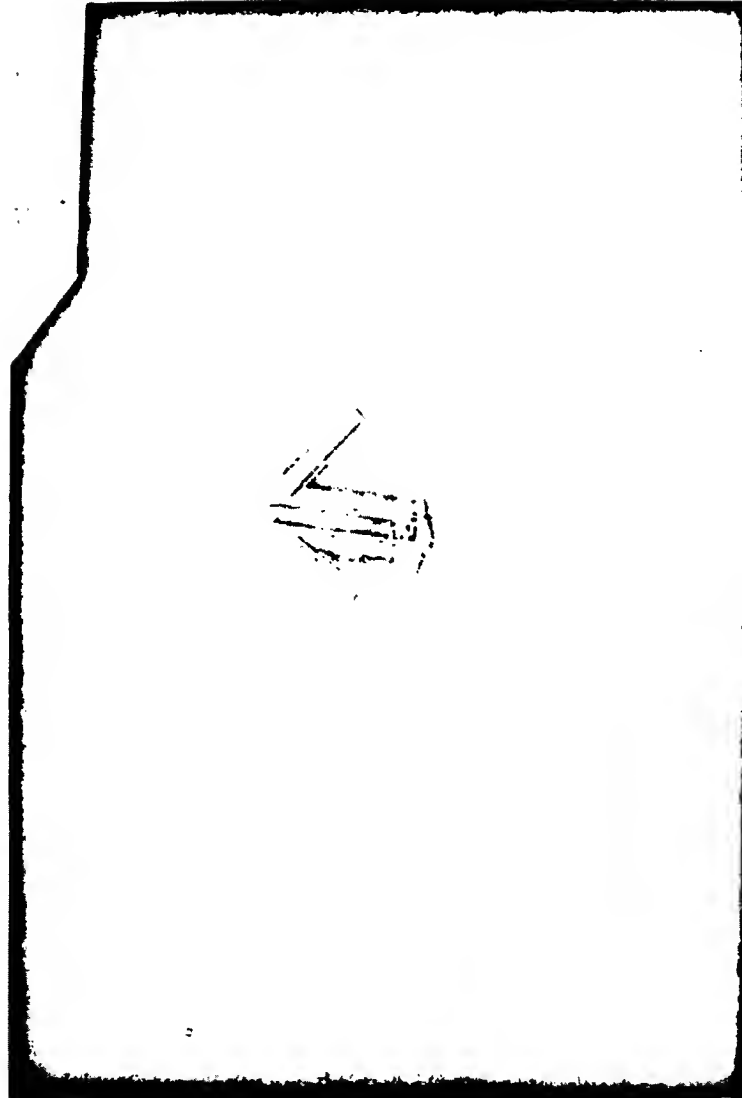
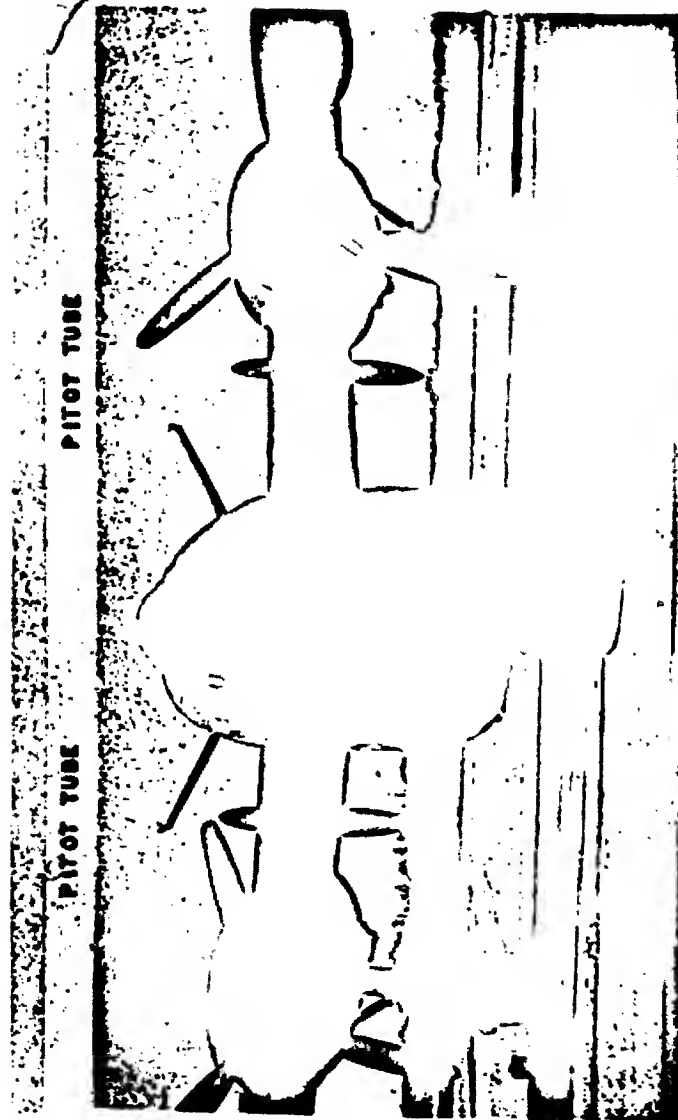


Figure 32. AS-69/APT "Fishhook" rotating polarization anti-Wurzburg radar antenna

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411-299



42300 ANTENNA SYSTEM ON 624-0

Figure 33. Twin stubs raked backward and fed through "bazooka", give horizontally polarized signal with maximum forward

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useful even against radars with moderately fast sweep speeds and moderately narrow beamwidths.

A more elegant solution to the direction-finding problem was the AN/APA-17 rotating-reflector direction finder. The final version of this equipment was remarkable for the fact that it displayed the received pulses directly on a long-persistence cathode-ray-tube screen thus making it possible to distinguish between two radars operating on the same frequency, and located not far apart. The instantaneous indication was also a great advantage where rapidly sweeping or intermittently operating radars were involved. Polarization of the incoming signal could be determined by the flip of a switch. The head normally provided with this equipment covered the frequency range 300 to 5000 Mc. By the end of the war, a low frequency head capable of operation down to 70 Mc, and high frequency head extending the range up to 10,000 Mc, were in procurement.

One interesting application of these direction finders was their use by the 8th Air Force to detect the position of enemy fire control radars. Lost formations, unable to fly the course previously worked out for maximum flak evasion, could use their APA-17's to warn them of their approach towards an enemy flak battery.

The shipborne version of the AN/APA-17 was known as the DBM direction finder. Using two heads, the coverage of this equipment extended from roughly 150 Mc up to 5000 Mc. Extension of the range to 10,000 Mc was in progress at the end of the war. Many difficult problems involving the mounting of these direction finders aboard ship had to be solved before they could be satisfactorily installed. However, tests showed that the problems could be solved, and many of these equipments were installed aboard Naval craft.

Test Equipment

RRL has always considered the development of adequate test equipment a job of importance equal to that of the development of the prime equipment itself. A number of equipments were developed by RRL's test equipment group; a few examples will give an idea of the types involved.

For the low frequency jamming transmitters, a small heterodyne-type frequency meter was devised. This item, the BC-1255A, was procured in some quantity by the Signal Corps and distributed for use with Mandrel (AN/APT-3) and Dina (AN/APT-1) transmitters. Also useful with the Dina-type equipments is the TS-92/AP Alignment Indicator, which also went into quantity procurement. The TS-47/APR test oscillator, developed by the General Radio Company with the assistance of RRL engineers, and handled as an RCM item by the RRL Transition Department, was designed for checking the performance of AN/APR-1 and AN/APR-4 receivers. Many delays were suffered before these equipments appeared in quantity. The TS-131/APT Transmitter Output Indicator, a small item which for best results should be part of each jammer installation, was eventually ordered in large numbers.

It must be emphasized that the quantity orders did not come until late in the war; when the test equipment was most needed in the field, it was seldom available. For example, barrage jamming transmitters for the invasion of Southern France were largely set on frequency by means of two or three General Radio commercial-type frequency meters carried as personal property by RRL technical observers. One basic difficulty was the fact that test equipment always enjoyed lower priority than the prime equipment it was designed to test. Another difficulty was the policy

of attempting to save effort by consolidating test equipments, designing each to service more than one type of equipment. This had the effect of slowing test equipment procurement down to the pace of the slowest prime equipment; RCM designers, as a consequence, had difficulty in seeing their test equipment into procurement even though the developments were ready in time.

Anti-Jamming

It was realized in the very beginning that anti-jamming research would be an important part of the overall countermeasures job. In the early days, when the Laboratory was endeavoring to find out what could be done to jam radars, it was equally important for the Laboratory to know what could be done to unjam them. Moreover, the early studies of jamming on various oscilloscope presentations (which had made possible the selection of the most effective type of jamming modulation), were not sufficient to determine the relative vulnerability to jamming of complete radar systems. For this reason, the Laboratory undertook to obtain, set up and operate samples of various radars in operational use. As soon as the first of these was in operation, a thorough investigation of the mechanics of jamming was carried out. It was soon found that the curious radar scope patterns caused by different kinds of jamming signals each had a logical explanation. This information served as a basis for operator training and for studies of circuits which could reduce the effects of jamming.

It was realized at once that operator training is a very important part of anti-jamming work. When confronted with new and unexpected equipment behavior, the normal reaction of the green operator is to shut down and look for trouble. However, if he is expecting jamming and knows what kind of effect it will have on his equipment, he will not be rattled, but will stay on the job, and may still get a good deal of information out of his radar.

In this realization a program of Service education was undertaken by the Laboratory. This was accomplished by means of various training aids - reports and technical manuals, motion pictures (valuable because they illustrate moving or changing patterns), training signal generators (i.e., signal generators with provision for various types of jamming signals), and training jammers (i.e., full power jammers also equipped with many types of modulation). Using these and other aids, RRL representatives carried out many demonstrations of countermeasures at Army and Navy operating sites and training schools, as well as at the Laboratory itself.

As a result of this work, the Services soon became aware of the possibilities of countermeasures and anti-jamming. The Army published a series of training pamphlets for radar operations. The Navy prepared training motion picture films, showing the effect of countermeasures on typical Navy radars. At Pearl Harbor, an extensive fleet operator training program was undertaken, and joint Army-Navy jamming exercises were carried out. When the Japanese began using Window during the later stages of the Pacific war, U. S. Navy radar operators were well prepared.

In addition to fundamental studies of anti-jamming, RRL undertook a program of investigating the specific vulnerability of various radars in common use. In a few cases, these studies brought to light some unsuspected and easily corrected vulnerability in certain specific radars. For example, it was found that the ability of the SCR-268 to track in elevation and azimuth could easily be thrown off by a very small amount of continuous wave jamming coming from a source not exactly

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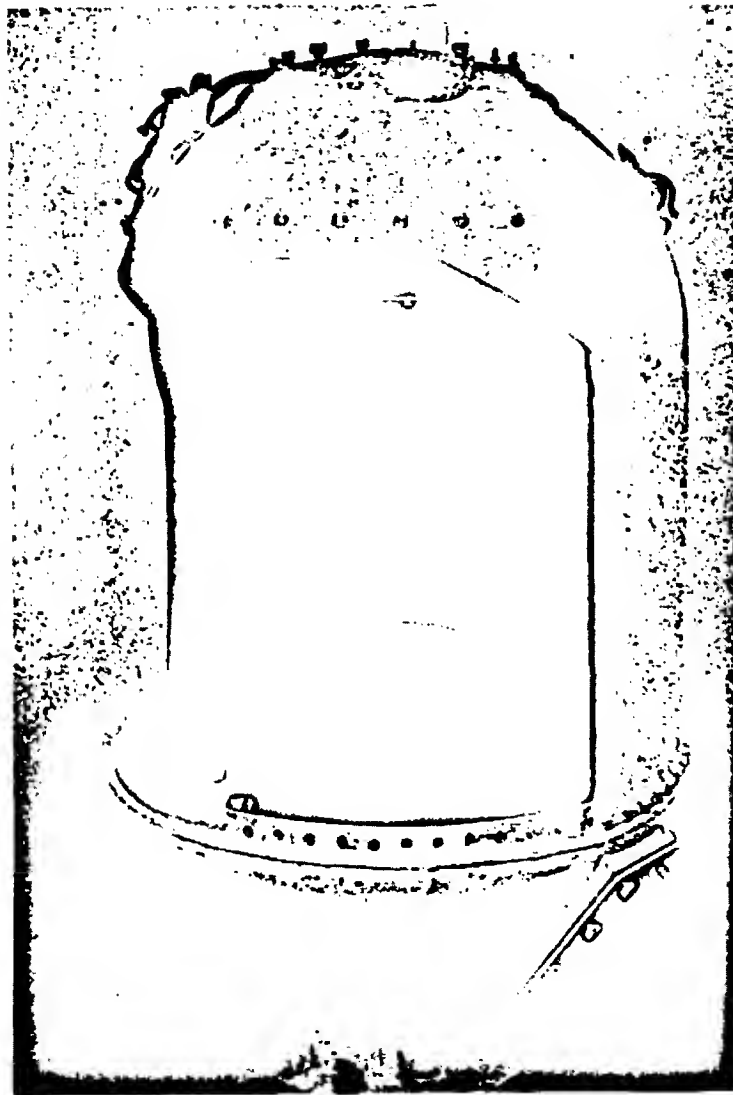


Figure 34. TDY-1A 10 Cm, circularly polarized
rotatable jamming antenna (cutaway view)

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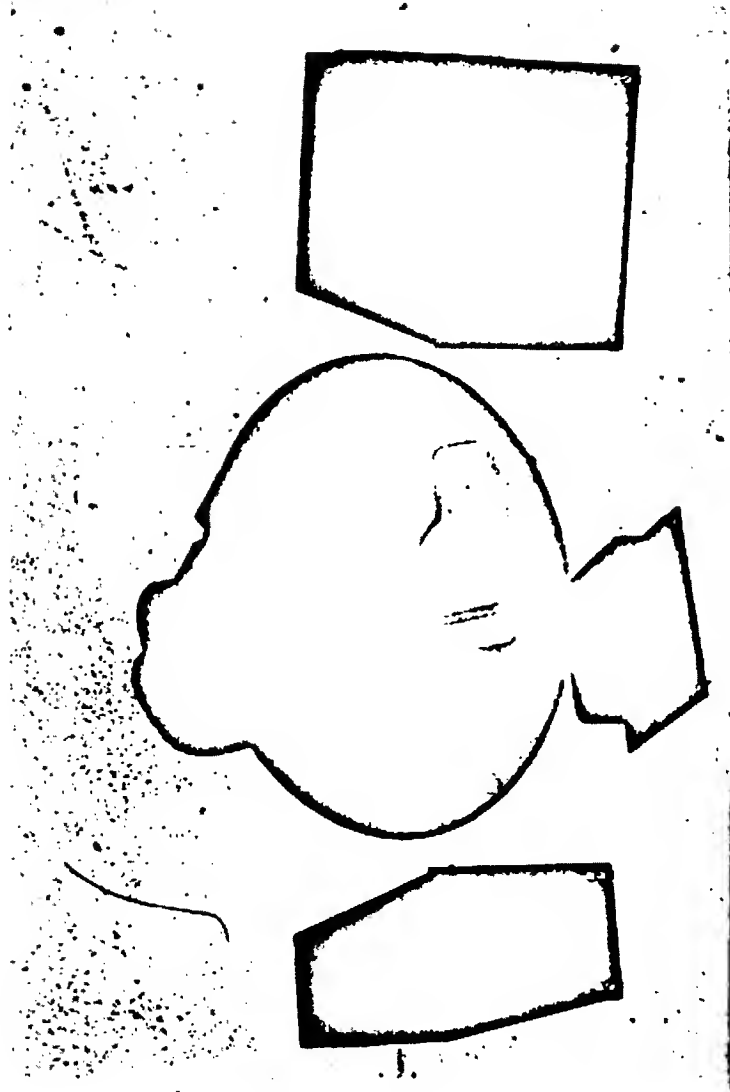


Figure 35. Components of AN/APA-17 rotating reflector direction finder

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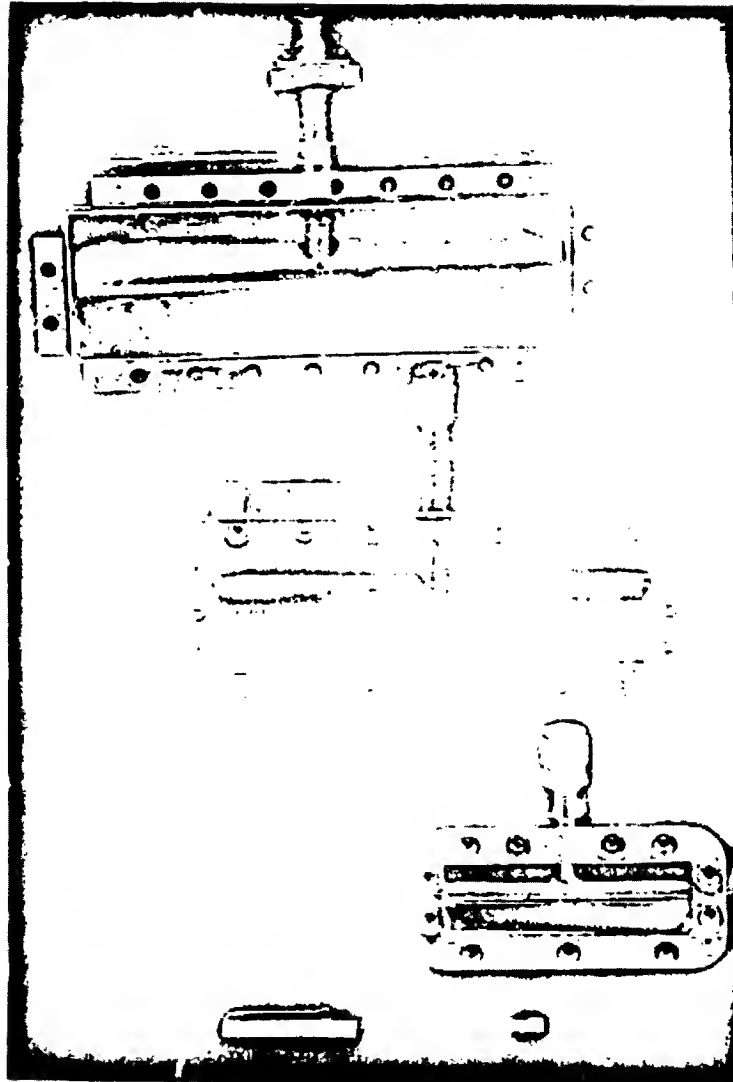


Figure 36. Wide-band "Slot" antennas like these can be mounted flush with skin of plane

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in line with the target. Again, the SCR-521 radar receiver could easily be overloaded by CW jamming. Both these defects could be corrected by means of simple plug-in attachments.

A working agreement was reached with the Radiation Laboratory, whereby RRL was responsible for A/J studies in the case of low frequency radars, and microwave radars not designed at the Radiation Laboratory. In the case of the radars for which it was responsible, RRL carried out basic studies and designed simple anti-jamming attachments in cases where this was feasible.

In general, microwave radars were found to be less vulnerable to jamming than long wave radars. They are relatively susceptible to jamming at the image frequency, however, because of the low radio-frequency selectivity of most microwave receivers. As might be expected, the PPI-type radar display is much more easily jammed than the standard A scope; in fact, operators were urged to use the latter as much as possible whenever jamming was encountered. Microwave automatic gun-laying equipments were found to be somewhat more susceptible to jamming than ordinary radars, due to the increased complexity of these equipments. RRL also made studies of radar glide bombs such as the "Pelican" equipment, which was found to be quite susceptible to jamming.

As a result of its work in the A/J field, RRL learned the limitations of anti-jamming and learned to what extent our own jamming could be made ineffective. In this way, certain plausible but, from an A/J standpoint, ineffective types of jamming modulation were avoided. In the end, it can be stated that the best anti-jamming is simply good engineering design and the spreading of the operating frequencies. The plug-in attachments which were used to improve the performance of some radars in the presence of jamming, in reality merely corrected for departures from good engineering practice.

The procurement of training equipment, like that of test equipment, was found to lag in a most unsatisfactory way. Very few of the RRL developments in the training equipment field were actually procured by the Service in any quantity as a result of the low priority enjoyed by this type of equipment. For example, it was almost impossible to obtain jamming transmitters for conversion to training jammers, since the jammers themselves were in such great demand on the part of the operating forces. However, the idea of operational countermeasures training was aggressively followed by the Services and in many instances, the necessary training equipment was improvised on the spot by field personnel.

VI. HOW THE WORK WAS DONE

Conduct of the Research

When the Laboratory was set up, the research program was broken down into certain well-defined categories, such as receivers, transmitters, microwave, anti-jamming, etc. An effort was made to find a Senior Staff member whose experience and abilities fitted him for the direction of a group specializing in each category. The group leaders reported to the Director, and the direction of the Laboratory's program was worked out at meetings of the group leaders (under the chairmanship of the Director), which came to be known as Senior Staff Meetings. The volume of business soon required that the meetings be of two types - one in which business matters were discussed, and the other in which the technical program was considered.

However, as the size of the Laboratory increased, the number of groups multiplied, and the size of the Senior Staff Meeting increased to the point where effective action at these meetings became difficult. This was the situation early in 1943; at that time, Service interest in the Laboratory was increasing rapidly, and Service project requests were being formalized and transmitted to the Laboratory through channels which were, for the first time, being established.

In order to coordinate and evaluate these incoming project requests, as well as to broaden the basis for making decisions, the Laboratory's Project Committee was set up in May, 1943. It was the task of this Committee to review each incoming project in the light of the Laboratory's existing work load, and to indicate the priority which should be assigned by the individual group in carrying out the work. All projects originating within the Laboratory were reported to this committee for their consideration, in the same manner as incoming projects requested by the Services.

At first, the Project Committee did not exercise a particularly strict control over Laboratory activities. When the Laboratory had first got under way, its assignment had been so incompletely defined that many of the research personnel were obliged to make their own decisions concerning desirable projects, and to go ahead with these without regard to Service interest. It was found that virtually every worth-while project eventually received the desired Service interest.

However, as time went on and the Laboratory's program became more clearly defined, the control exercised by the Project Committee gradually increased. An important factor in this circumstance was the perennial shortage of shop and drafting man-hours which made close scheduling necessary for greatest effectiveness. The Project Committee, by allocating shop and drafting schedules and priorities, exerted a considerable influence on the course of the research work in the Laboratory.

The Project Committee also served as a central clearing house for information affecting the Laboratory program. Copies of teleprinter conference minutes, reports of liaison representatives, letters from Technical Observers, etc., were circulated to members of this committee. In this way, the committee was kept abreast of changing Service requirements, and other changes in the overall program.

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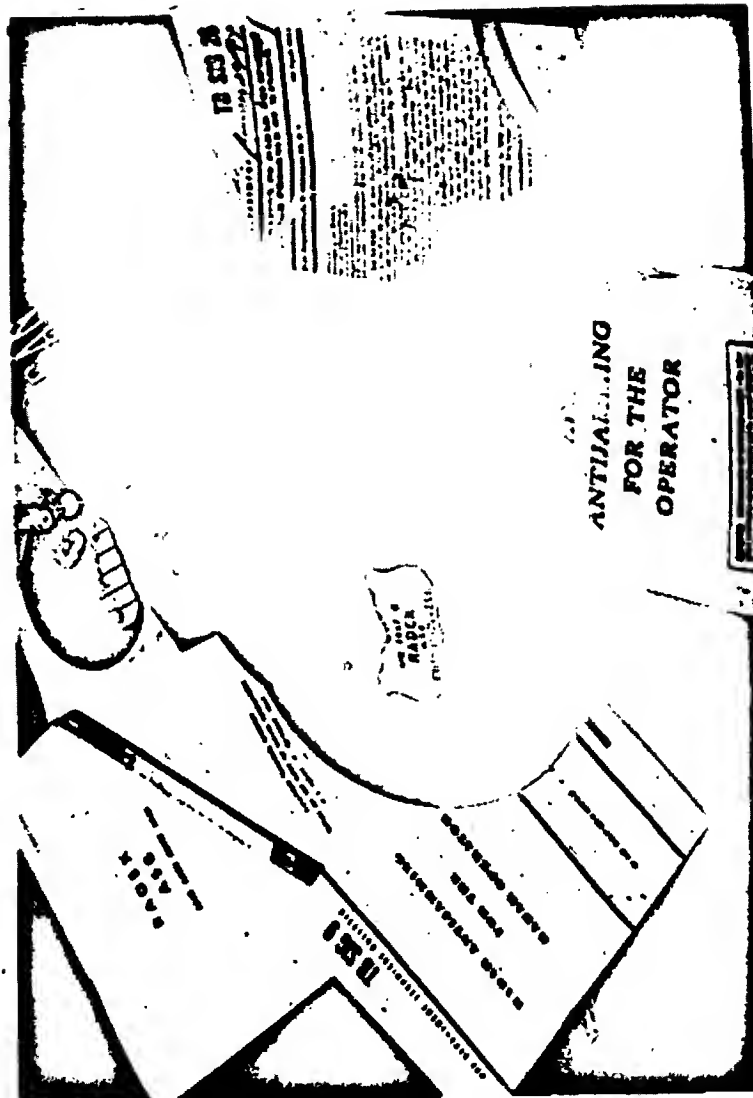


Figure 37. The services were actively interested in anti-jamming training

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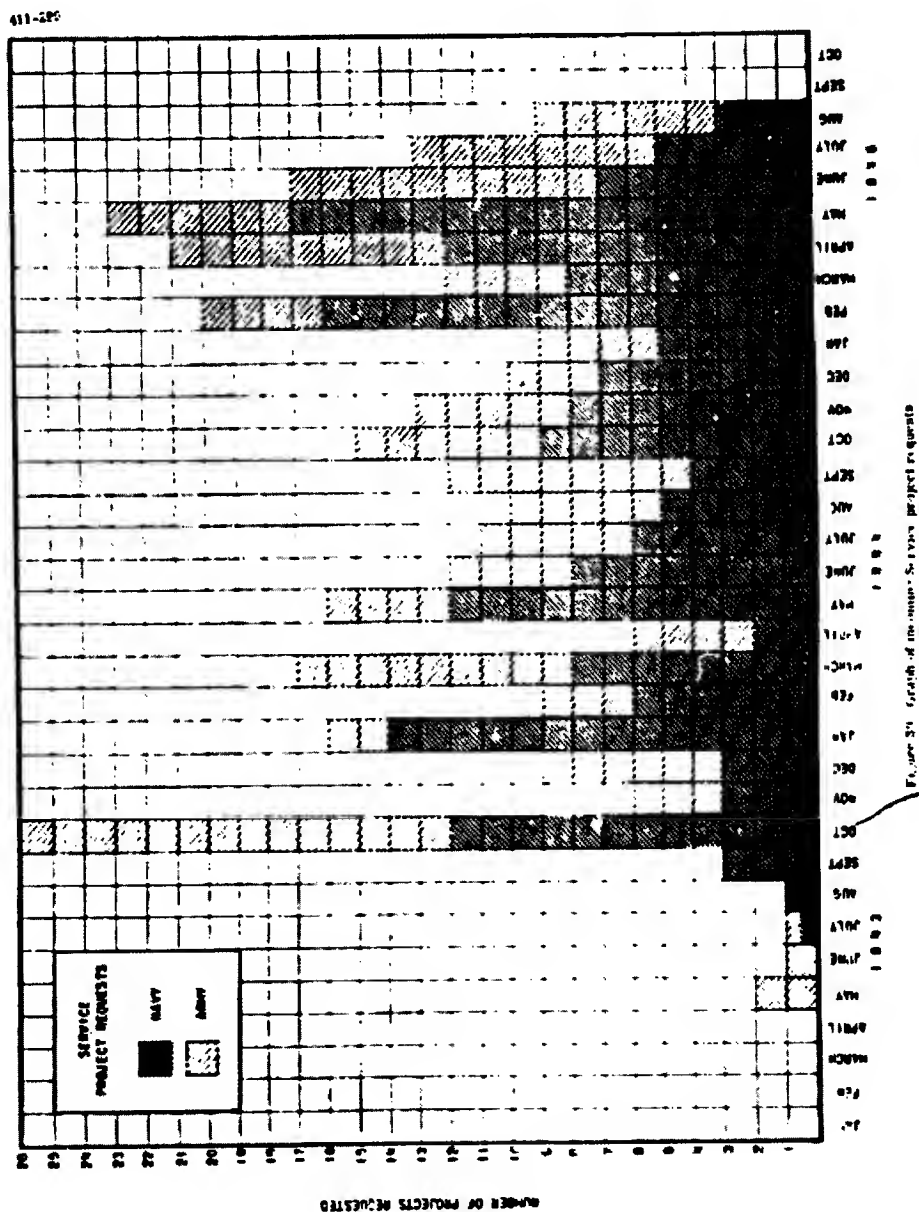


Figure 38. RRL helped train the Services in the use of new equipments

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NUMBER OF PROJECTS REQUESTED

CONTINUUM



As the number of individual Laboratory groups still further increased, it became necessary to delegate more of the Director's responsibilities. The main branches of the Laboratory's activities were consequently broken down into divisions, which included one or more groups. Such divisions included the Transmitter Division, the Receiver Division, the Production Division, etc. Heads of the divisions were represented on important committees which, in turn, were under the chairmanship of the Director.

Much of the Laboratory's technical program was worked out in committee meetings. In the Transmitter Committee, the status of the Laboratory's transmitter development program was periodically reviewed and the capabilities of the Laboratory equipment considered in the light of existing or probable Service requirements. The Receiver Committee served a similar function, as did a Test Instrument Committee. During the latter stages of the war, when the Laboratory's emphasis shifted increasingly to short-range projects aimed at assisting in the operational use of RCM equipment in the field, a Field Test Committee and then a Field Division was formed which coordinated this phase of the Laboratory's work and maintained contact with the Laboratory's field stations in Bedford and Florida.

In general, while details of the program were decided at the technical committee meetings, overall Laboratory policies were decided at the Project Committee and, for a time, at what was known as an "Executive Committee" modeled after steering committees found in other organizations. The Executive Committee considered administrative matters such as personnel policies, etc. This committee eventually became inactive and was succeeded by a smaller Management Committee composed of the Director, Associate Director, Executive Engineer, and Business Manager. The Division 15 Technical Aide participated in all committee discussions as a welcome "guest".

To coordinate the Laboratory's equipment development program, Mr. John F. Byrne was named Executive Engineer in the fall of 1943. Reporting directly to him were the majority of the groups in which apparatus was being developed for production. The choice of Mr. Byrne as Executive Engineer was a happy one in view of his extensive experience in industry, which proved invaluable to the Laboratory.

Liaison

Civilian-controlled war research laboratories, such as RRL, are in a position to make a unique contribution in wartime. In contrast with laboratories operated by the military:

- (1) A civilian organization can serve all branches of the Service in accordance with their greatest need.
- (2) Civilian status makes possible dealing with the military at all levels in the chain of command.
- (3) Freedom from travel quotas and other restrictions makes for greater mobility - civilians have less difficulty in traveling wherever their duty requires.

The above circumstances represent tremendous privileges which are clearly not to be abused. If properly taken advantage of, however, these privileges can make the wartime contribution of a civilian research organization many times more effective than would otherwise be the case.

CONFIDENTIAL

It was found, early in the history of RRL, that in order to carry out an intelligent program, a tremendous amount of contact work was required. Not only was it necessary to keep abreast with new technical developments in the field; it was necessary to find out a thousand other things with a bearing on the program as well.

In the early days of the Laboratory, the immediate problem was to find out what, if anything, could be done with radar countermeasures. It was by no means clear that a single black box carried in an airplane could actually protect that airplane against radar observation. Contact with research organizations in the field was, in general, sufficient for the direction of the Laboratory's program. Consultation with Service officers was less important since in most cases they themselves were new in their jobs and - like the researchers - not too well acquainted with the possibilities of RCM.

In those days, many valuable contacts resulted from trips made to other Service laboratories. Meetings of Service and NDRC committees (such as the Countermeasures Committee, which served a useful function as a central coordinating and policy-making body) provided Laboratory personnel with opportunities for informal contact with those connected with the various phases of the RCM program.

By the early spring of 1943, well after the Laboratory's first three developments (Autosearch, Mandrel, Carpet), had gone into procurement, the complexion of the overall liaison problem began to change. In terms of research personnel, the Laboratory was at one-half its final strength in January of that year. The pace of the work was rapidly increasing, and new developments began to appear at a correspondingly greater rate. Moreover, the armed Services were acquiring a greater awareness of the importance and the possibilities of RCM; the number of agencies interested in RCM increased; project requests began to pour in, and project officers became frequent visitors of the Laboratory. The enhanced scale of activity multiplied the number of technical decisions to be made, and the increased Service interest brought to light many questions of policy and program direction.

In order to handle systematically this increased Service interest, as well as to assist with the formulation of a Laboratory program that would serve the best interests of all branches of the Services, certain additional steps were taken. An RRL liaison office was set up, to serve as the nucleus of the Laboratory's liaison activities, and to maintain contact with the many Service agencies now affecting the RCM program. Not long thereafter, Mr. A. E. Cullum, Jr., who was responsible for the Laboratory's liaison activities, was accredited to the office of Dr. E. L. Bowles, Special Consultant to the Secretary of War, thus placing RRL's relationship with Army agencies on a more formal and official basis than had previously existed.

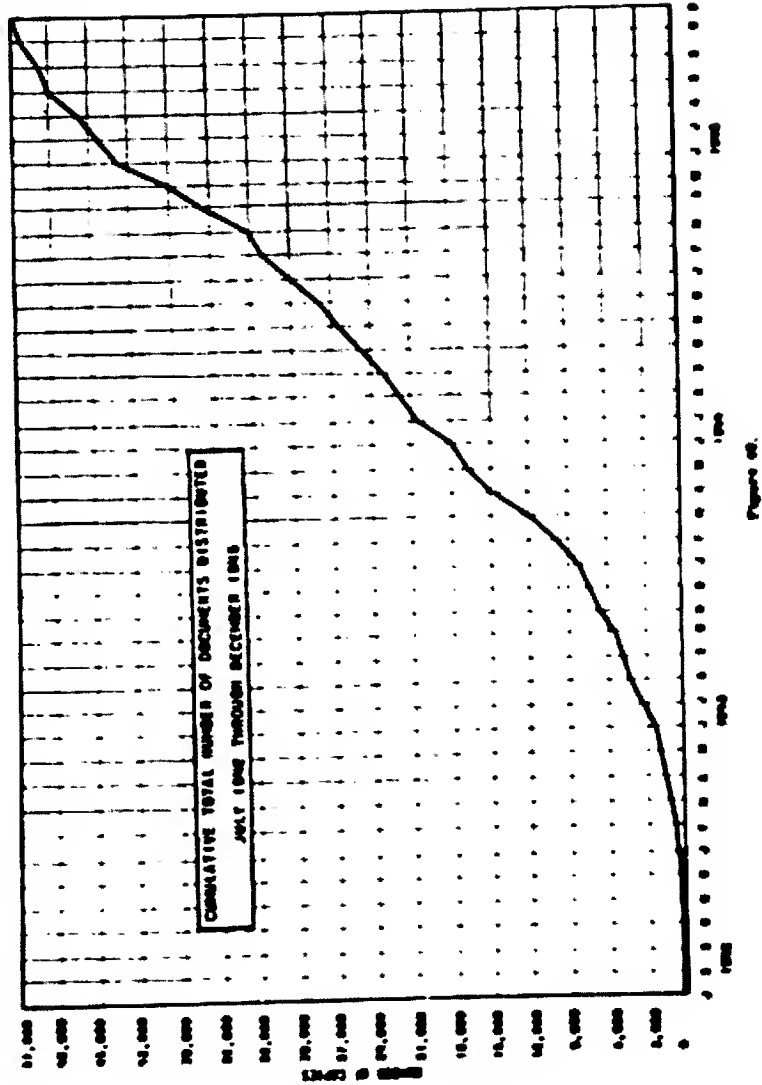
For the benefit of Service project officers whose business took them to RRL, a regular series of "Informal Liaison Conferences" were begun at the Laboratory in February, 1943. These conferences, which were attended by representatives of all the interested Service branches, provided excellent opportunities for the review of Laboratory developments in the light of the varying Service requirements. Thus it was often found that specific RCM developments, as was the case with many other electronic equipments, could often be used by all branches of the Army and Navy with very little modification.

Since the Service interest in, and demand for, RRL developments often far exceeded the Laboratory's ability to translate the requirements into specific

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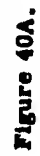
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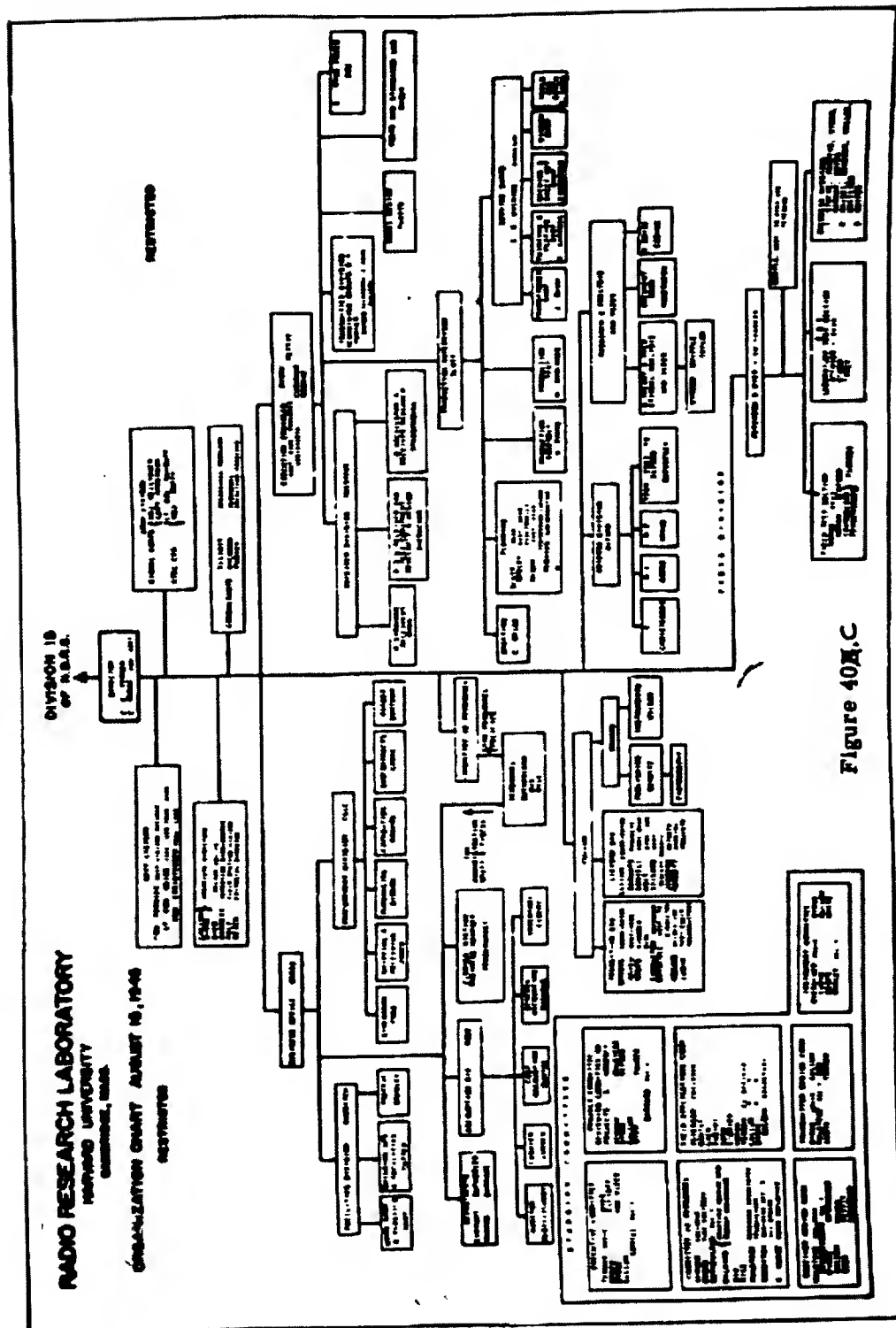
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equipments, the Liaison Conferences provided a place at which the priorities to be assigned various phases of the Laboratory's work could be reviewed. In this way, for example, if satisfaction of an urgent Navy requirement meant delay to a development being carried out for the Army, the matter could be reviewed and Army concurrence obtained.

The need for frequent Liaison Conferences increased as the war went on and the design of many of the basic RCM developments became frozen. These meetings were eventually replaced by informal evening gatherings in Washington which came to be known as "smoke-filled sessions." At these meetings, key Service and Laboratory personnel met to discuss the general direction of the countermeasures program in the light of the current war situation.

In 1943, as more and more RRL equipment passed through the manufacturing stage and went into operational use, the requirements for systematic liaison considerably increased. It was found, for example, that the chain of activities through which RRL developments had to pass between the research stage and their appearance in the field, was far longer than had been anticipated. Moreover, the normal Service reorganizations and shiftings of command required constant monitoring.

To give some idea of the complexity of the problem involved, a typical RCM development, after leaving RRL, would be sent to a Service Laboratory for a performance test. If it met the electrical requirements, a contract would then be let to a manufacturer, which would eventually result in the appearance of a manufacturer's prototype. This prototype itself then had to be tested for mechanical strength, shock, vibration, etc., before the full scale production could get under way. After that, the production equipments had to be shipped through a variety of depots before being sent overseas. At some of these depots, such things as accessories, spare parts, etc., were added; at others, they were boxed for overseas shipment. At any point in this long chain of events, the slightest slip-up could mean delay to equipment vitally needed in the operating theaters.

By maintaining contact with its developments at every stage, from testing of the prototype to shipment of the final packaged equipment overseas, the Laboratory was able, in many instances, to assist and expedite matters. Here the relative mobility of civilians proved invaluable. Apparently harmless delays and bottlenecks, which might develop at some step in the chain far down the line, would not normally reach the attention of the officers charged with overall responsibility for the program. Civilians, however, were in a position, when it was appropriate, to call difficulties to the attention of those concerned, and thus to obtain quick action.

Another valuable service rendered by Liaison personnel was the matter of coordinating project requests. In view of their number, new requests had to be scrutinized with care to determine their relative importance and priority in relation to the rest of the Laboratory program. A tremendous amount of evaluation had to be carried out, since it was perfectly possible for a junior officer in the field to originate a requirement to Washington, signed by the theater commander, for a development based on incomplete or misleading information. These theater requests could not, of course, be ignored, and were usually sent on to the NDRC. In each case, Laboratory Liaison representatives saw to it that a thorough study of the merits and demerits of each request was made, and that the Laboratory's decision on the basis of these results was promptly reported back to the originating agency for transmission to the theater.

CONFIDENTIAL

111-299

The extreme secrecy which surrounded the radar countermeasures program from the very start, made it necessary that a considerable amount of indoctrination be carried out as countermeasures equipment traveled down the long "pipeline" between the Laboratory and the field. In addition to assisting manufacturers in every way possible, the Laboratory was able to save much time, trouble and confusion by contacting training, supply, and installation agencies concerned with the RCM program, and by keeping them informed of the latest developments.

It frequently happened that Service plans for the use of a particular development would change without warning, sometimes without the knowledge of the Service agency which had originally made the request to the Laboratory. Decisions of this sort were not infrequently based on incomplete technical information and on an incomplete understanding of the purpose for which the development was intended. By keeping in touch with the progress of Laboratory developments at every stage in their career, RRL was able to render a great service in preventing misunderstanding and in straightening out difficulties in a minimum of time. As an example, procurement of one of the Laboratory's jamming transmitters was at one time cancelled by the Services on the basis of inadequate information in regard to the power output and the proposed application of this equipment.

As the war went on, and more and more RCM equipment arrived in the field, the need for field assistance greatly increased, and the number of RRL personnel on duty overseas became proportionately larger. Consequently, a need arose to coordinate their activities and to secure quick action at home on the basis of their findings. Here again, organized liaison played an important part.

Of inestimable value to the program as a whole were the overseas teletype-writer conferences, carried out at regular intervals from Army Air Force Headquarters in Washington, D. C. These conferences with important field headquarters such as United States Strategic Air Forces in Europe, etc., gave those at home an up-to-date, clear picture of theater problems and requirements, and at the same time provided the eventual consumers of countermeasures equipment with the latest data on developments at home. In addition to these conferences, RRL technical observers overseas made a series of regular reports to the Office of the Air Communications Officer. As a result of the follow-up provided by the Laboratory, each RRL representative on foreign duty could rest assured that questions raised in his reports either written or teletype, would receive considered attention at the Laboratory and would also be relayed to the appropriate Service organization for action.

A classic example of the usefulness of an organized Liaison activity is to be found in the story of the assistance rendered to the United States Strategic Air Forces in Europe in connection with the supply of Carpet jamming transmitters. The first of these had been shipped to the theater in the summer of 1943, and had immediately proved their effectiveness in combat. Quantity orders followed immediately thereafter. The 8th Bomber Command, which in 1943 was at approximately one-third full strength, was brought up to its final size by June of 1944. With more than 3,000 first-line heavy bombers on hand, the 8th Air Force had at its disposal in August, 1944, no more than 250 operational Carpet jamming transmitters which, for best results, should be carried one-to-a-plane!

Yet according to information received from the manufacturers, some 4,000 Carpet transmitters had been delivered in the United States. Two reasons were eventually discovered for their non-delivery to Europe; one was a general lack of understanding of the chain through which manufactured equipments had to pass before

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Figure 41. Main drafting room

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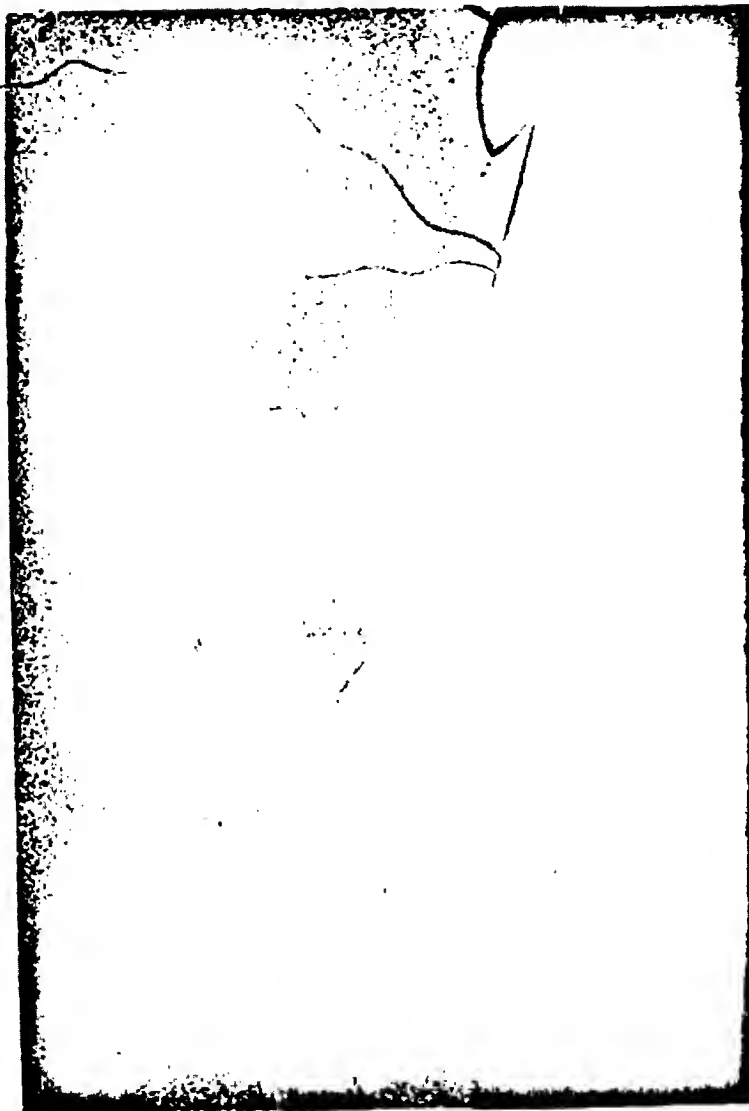


Figure 42. AN/APA-24 direction-finder top mounted on a B-24

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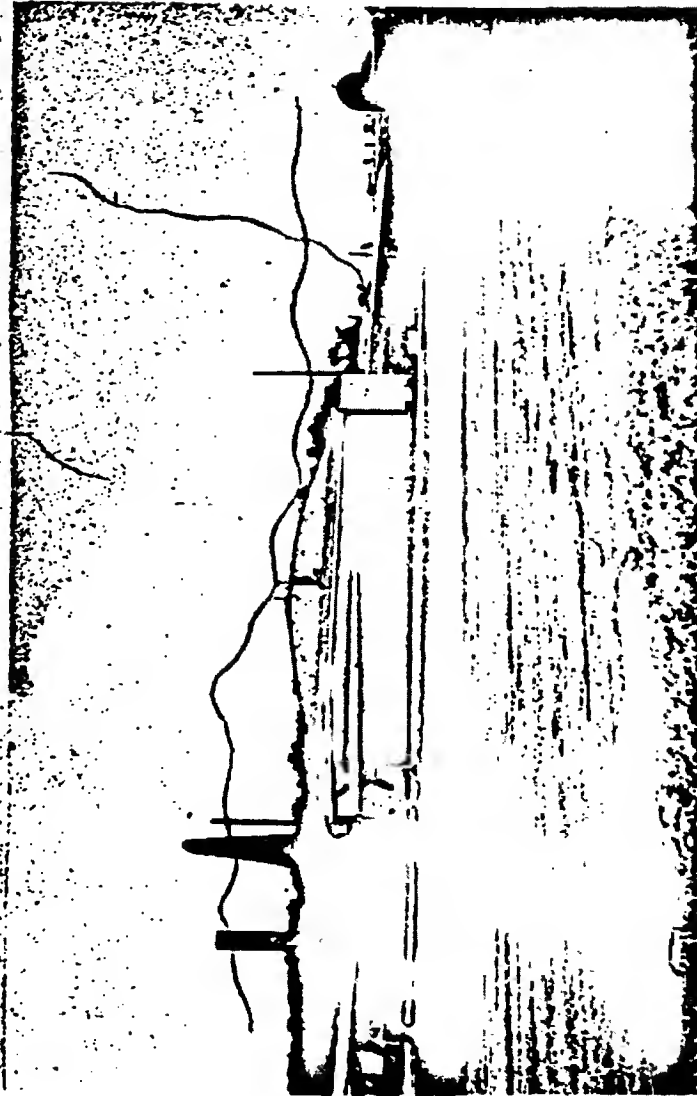


Figure 43. View of the RRL Hangar at the Bedford Airport

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their delivery to the theater. The other was a specific "bottleneck" in the supply organization whereby the shipment of thousands of countermeasures equipments was handled as a sideline. In the summer of 1944, Radio Research Laboratory Liaison representatives carried out a detailed study of the causes for the delays being encountered in the shipment of Carpets to Europe. When their findings were called to the attention of the officers responsible for the various phases of the supply activity, immediate and very gratifying action was taken. Shipments from warehouses to depots were expedited, and a system of control set up whereby responsible officers in Washington could maintain a day-by-day check on the flow of equipment to the field. Meanwhile, in the ETO, plans had been made for the expedited handling of the equipment when it reached the theater, and by October, 1944, a substantial proportion of the 8th Air Force was equipped with the long-awaited jamming equipment. By November and December of that year, every heavy bomber based in Britain was equipped with one and in most cases two, of these jamming transmitters. The havoc these equipments raised with the German radar fire-control apparatus is described in Chapter VII.

Still later in the Laboratory's career, when the eventual outcome of the war became more or less obvious, the direction of the Laboratory's effort was shifted from long-range research to those shorter-range projects which still held the prospect of seeing service in time. The need for Liaison was still further increased since it became imperative that the delay between the formulation of a need or requirement and its satisfaction, be cut to the minimum. As the number of reports from agencies employing RCM equipments in the field increased, the flow of this material to Washington became so large that in many instances it became physically impossible for the agencies interested in RCM to pass along data of interest to the Laboratory. Early in 1945, the Laboratory increased the scale of its Washington liaison activities in order to take these factors into account. In this way, the Laboratory was kept well enough informed to take quick and effective action.

The internal procedure for handling the vast amount of information brought to light by the Laboratory's formal and informal Liaison activities hinged around the RRL Project Committee. Each Laboratory representative attending meetings, or making visits where matters of general interest to the Laboratory were discussed, wrote up the significant points in the form of a memorandum to the Project Committee. This committee, meeting weekly, then reviewed each memorandum with its author so that the points raised could be discussed with those responsible for the overall direction of the Laboratory's program. Information received by the Committee was also widely circulated within the Laboratory.

It was an established Laboratory policy not to act on behalf of one branch of the Services without consulting the others, since all branches were affected to some extent by almost any action. Of great assistance to this procedure was an additional Laboratory policy to keep supplying the Services with the latest technical information, through the medium of conferences, personal visits, phone calls, etc., thus keeping Service thinking up-to-date in terms of technical realities. By acting on behalf of all branches, RRL was often able to serve as a catalyst, or means of crystallizing a joint Service program.

The Laboratory always considered it a basic assignment to see that a plan of action existed, and then to make sure that action was taken according to that plan. If RRL had a proposal, it would be brought to the attention of all branches of the Services concerned, and a decision requested. If the proposal was rejected, the matter was dropped. If the proposal was accepted, the Laboratory made sure that the plan was fully implemented.

CONFIDENTIAL

As time went on, Service confidence in RRL's technical judgment steadily increased. In this connection, the RRL Test Laboratory played an important part by standardizing measurements and specifications, thus enabling RRL representatives to make technical statements of demonstrable accuracy.

Moreover, when RRL was required to reject a Service request, a special effort was made to acquaint all those concerned with the reasons for the negative answer. In time, many of the Service agencies gained confidence in RRL's judgment and accepted the Laboratory's decisions without question.

RRL came to be consulted informally, as well. As a result of discussions with RRL representatives, mutual agreements were often arrived at informally. When these agreements were later implemented with formal correspondence, all concerned were in complete understanding in regard to the intention of the correspondence. In this way, time was saved and misunderstandings were avoided.

Transition

Of importance equal to the task of developing new equipment, is the matter of placing the equipment in production in the shortest possible time, for the value of a research laboratory's contribution to the war effort is properly measured by the number of developments which actually saw service, rather than by the total number of developments completed. This criterion, of course, is a severe one in the case of a rapidly changing field such as countermeasures, in which the need for new developments depended on two tactical situations - United States and the enemy - instead of just one. In this way, the chances were doubled that the need for a new development might evaporate in the time required to place it in service in the field. Consequently, it was an RRL policy to help with the introduction of its developments whenever possible. It has been found that a development agency such as RRL can provide extra assistance in expediting production of new equipment in the following ways:

First, the number of equipments to be manufactured - that is, the Service requirements for a new development - can seldom be properly formulated without a trial of that new equipment in the field. By supplying models which can be tested by the operating commands in the various theaters, it is possible to determine their usefulness, and the number which will eventually be required, without waiting for the regular production to come along.

Second, in cases where an urgent operational need exists for small quantities of new equipment which cannot be obtained in time through any regular production, the development laboratory can frequently render an important service by hand-building a few models for expedited shipment to the field. These are known as "crash programs."

Third, the production of any new electronic development, especially those employing techniques different from those common in the industry prior to the war, can be aided by giving the manufacturer technical assistance. The developing agencies can render a valuable service here as well.

The NDRC, recognizing the importance of these considerations early in its history, had, by 1942, a well-defined "Transition" program and organization. Moreover, in 1943, previous informal consulting work was formalized in a statement setting up a "Consultant Advisory Service". According to this plan, the development agencies would render consultant or advisory service to the Services upon

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Figure 44. RRL technical observer briefing flight crews on countermeasures

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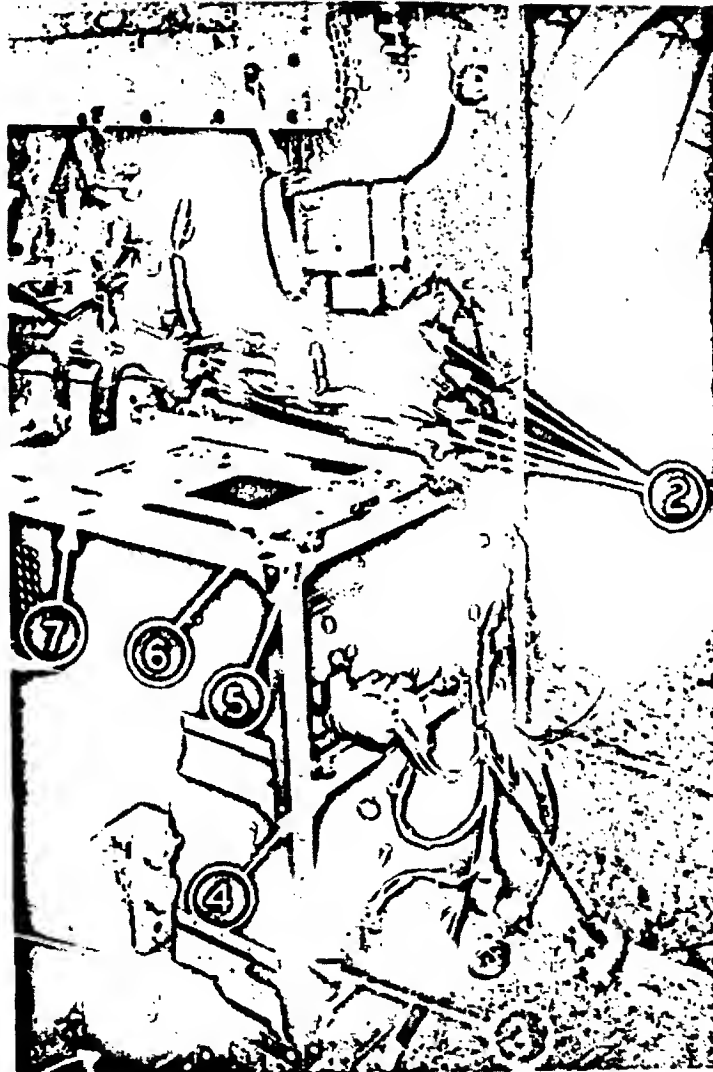


Figure 45. From an Army installation photograph:
barrage Carpets in a B-17

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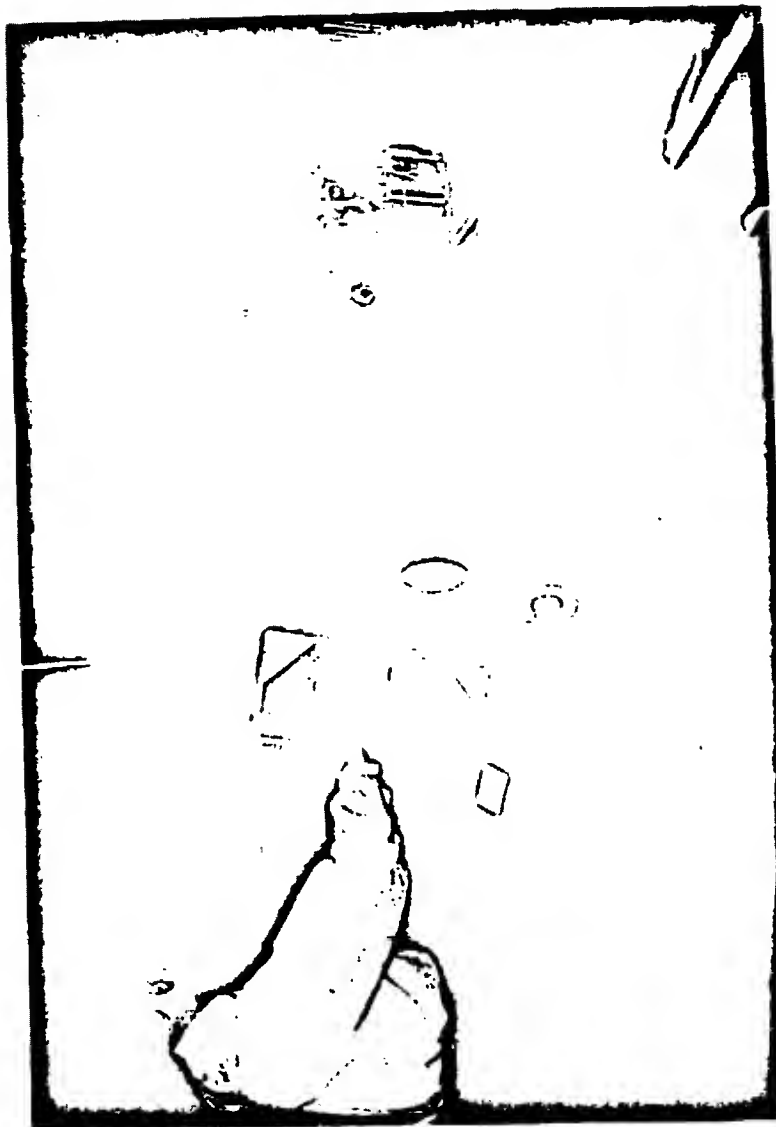


Figure 46. Radar anti-jamming study in progress

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receipt of a formal request for aid in manufacturing a particular product. Certain specified procedures would then be followed. The RCM program, with its greater-than-usual requirement for speed, fitted in well with the already established NDRC procedure. However, there were certain differences which were the outgrowth of the particular experience of the Laboratory.

All Transition work at RRL was coordinated under the Transition Department, which was set up late in 1942. RRL engaged in the production of models from the very start. As soon as it became apparent that carrying out work of this sort in the development groups would represent a considerable drain on facilities which were better used in other ways, provision was made for the production of models elsewhere. In late 1942, RRL took advantage of the facilities of the Research Construction Company, a model shop facility set up by the Microwave Committee (later Division 14) of the NDRC. However, the desirability of carrying out model construction at a location convenient to the research groups gave rise to the formation, in April, 1943, of a group within the Laboratory whose primary assignment was the production of models.

The average number of models constructed of each equipment was of the order of twenty. Of these, one would go to the manufacturer, approximately two would be kept at RRL for test purposes; two more would be shipped to Service laboratories for acceptance tests; two more would be reserved for trial at field testing stations within the United States; one or two would be shipped to RRL's field laboratory in England, and the remainder would be allocated to various interested branches of the Services, usually in quantities of one or two to each theater, which might have a requirement for the particular development.

Since the number of models to be built frequently exceeded the capabilities of the Laboratory's own shop, work was subcontracted to manufacturers, some near at hand, and some located further away. In cases where speed was essential, those near at hand were selected. A definite effort was made to pick manufacturers who might later be designated by the Services for regular production of the item in question. However, this was not always feasible, as a manufacturer capable of large-scale production was not always interested in making a small number of models unless guaranteed a larger order to follow - a guarantee which, of course, could not be given.

Care was used in seeking out and selecting manufacturers whose facilities fitted them for the particular job in hand. In general, the RRL internal model shop was reserved for the higher priority models, or "crash" items.

When asked to satisfy urgent operational requirements for small numbers of equipments, RRL undertook to assist the Services in whatever way was possible. Since it turned out that placement of a Service contract for even a small quantity of equipment generally consumed a considerable length of time, RRL was able, in some instances, to assist the Services by placing its own contract for the needed apparatus. In such cases, OSRD was eventually reimbursed by the Services for the equipments delivered. In other cases it was necessary that the development itself be either manufactured or modified in the Laboratory's own model shop; many weeks and often months could thus be saved in getting out a small quantity of equipment. The time saved usually depended on the size of the production involved, since the length of time required to get equipment into production is often directly proportional to the number of equipments which are eventually manufactured. Very close liaison was of course required for crash programs: many problems of precedence, etc., had to be straightened out, and here again the mobility of the civilian helped greatly.

In 1944, an internal RRL crash procedure was worked out whereby a three-man team - one representing the development group, one the Transition Department, and one the RRL Business Office - was given complete responsibility for the conduct and successful conclusion of the project. By working shoulder to shoulder, the three men represented a group small enough for effective action and yet large enough to assure excellent coordination.

The Army also developed its own crash procedure in 1944; according to this arrangement the normal chain of events was speeded up, and in some instances circumvented. So good was this procedure that contracts could be in the hands of the manufacturer four days after a model of the item to be crashed had been satisfactorily demonstrated at Wright Field. In the case of each item to be crashed, the development laboratory supplied an engineer who put in full time at the manufacturer's plant, to assist the manufacturer's representatives and the Army project officer in every way possible.

The special features of the RCM program were recognized by all concerned from the start. According to an early arrangement, two manufacturers, (Delco and Galvin), were to be held in reserve especially for RCM. According to the early procedure, engineers from the manufacturer were cleared, and when a development was nearing completion, would work in cooperation with the development engineers in the Laboratory groups. It was found that this type of arrangement was either extremely satisfactory or extremely unsatisfactory; if the engineers concerned proved to be congenial and capable of working together in a group, the results were remarkable; for example, the first models of the Carpet I transmitter were produced by the manufacturer in record time as a result of this arrangement.

However, in other cases, the manufacturer's engineers felt that their time was very largely wasted in the Laboratory, since there was little that they would do until the final design of the model had been frozen. Only then, for example, could the manufacturer order the necessary parts with the assurance that they could actually be required in the final model. The time required to secure the necessary components represented the largest delay in getting a new development into production.

As a result of a very understandable tendency on the part of most development engineers in the Laboratory to improve their models after their nominal completion date, it was found desirable to institute a procedure whereby a model was not "frozen" until the leader of the development group made that decision. At that time, the drawings, parts list, etc., necessary for a manufacturer to duplicate the model, were prepared in the form of what was called a "Transition Memorandum Report" (TMR). After preparation of this informal report, no further changes in the design were permitted without the express concurrence of the Laboratory, the Transition Department, the manufacturer, and the Service concerned. In this way, much lost motion on the part of the manufacturer was avoided, since last-minute changes likely to hold up production were eliminated.

After the completion of the TMR, responsibility for a project passed into the hands of the Transition Department engineers assigned to the work. The Transition engineers then had full charge of all relations with the Services and with the manufacturer from that time on. It was the Transition engineer's job to keep in touch with the progress of the development at the manufacturer and see that every possible assistance was rendered. It was a task which called for frequent personal contact and continued follow-up. If the manufacturer ran into any technical difficulties which required help from RRL, an engineer from the development group was designated to accompany the Transition engineer to the manufacturer's plant for the necessary length of time.

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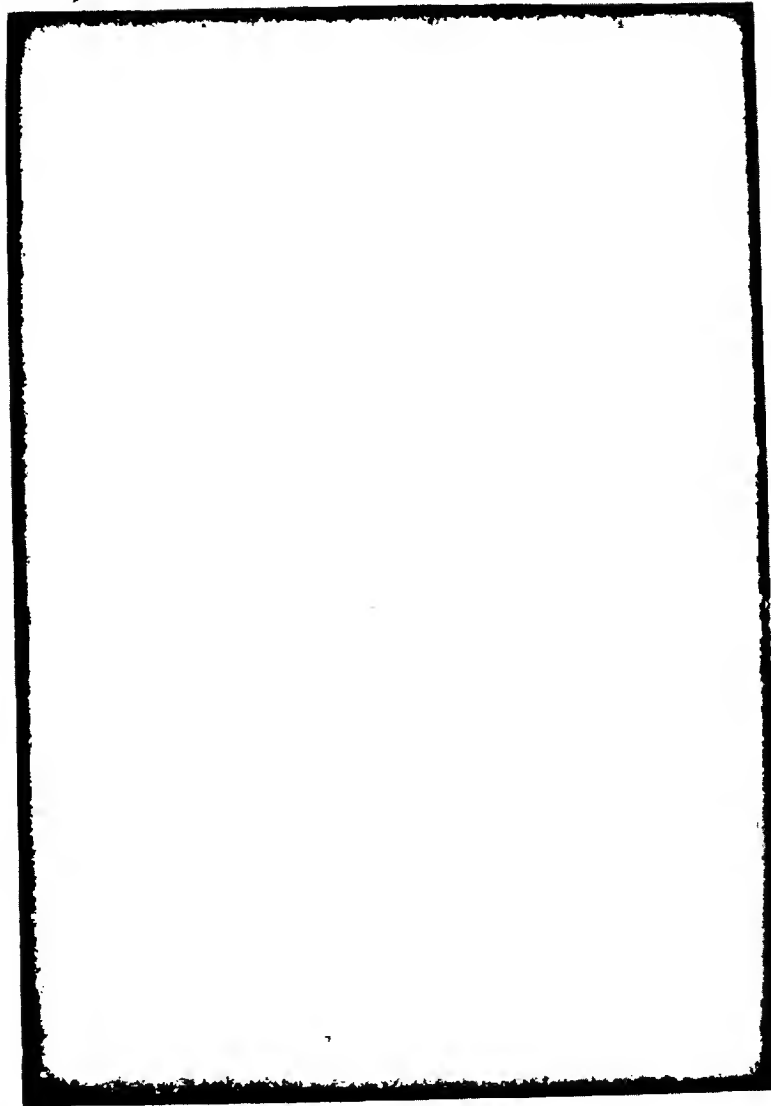


Figure 47. Closeup of circularly polarized microwave jamming antenna (M4902)

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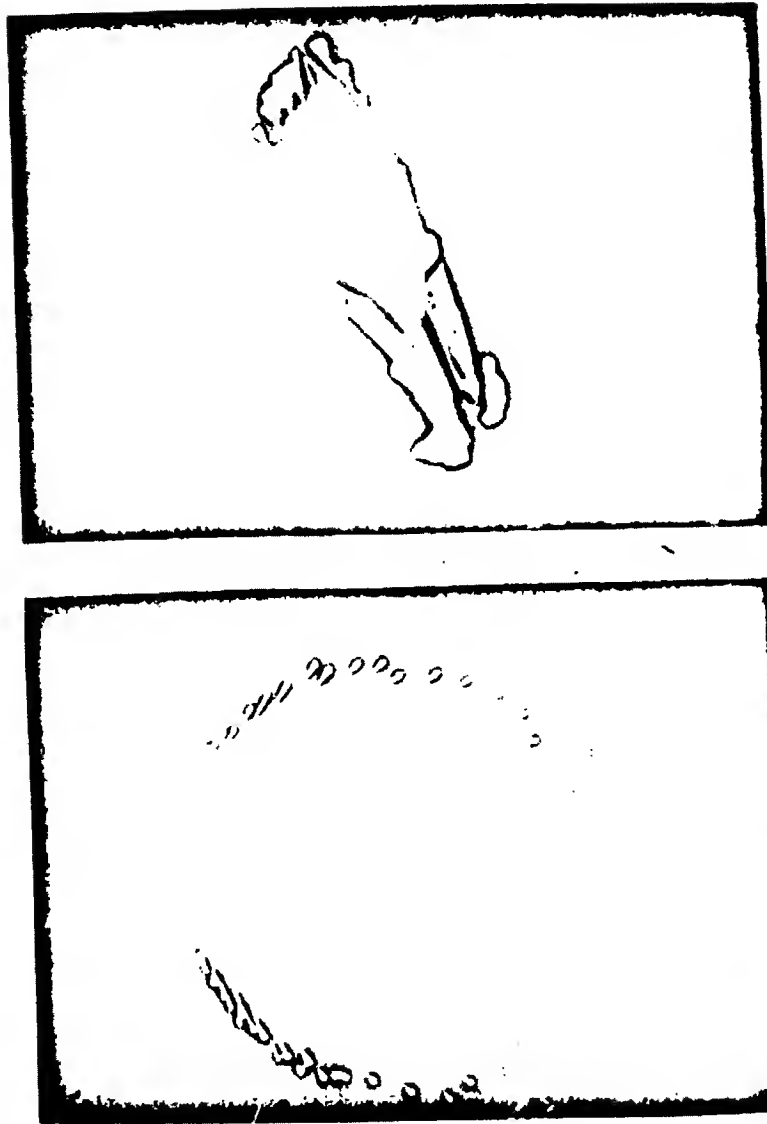


Figure 48. Representative AN/APA-17 scope patterns - low and high frequency

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The RRL philosophy throughout was to provide the manufacturer with as complete and satisfactory a prototype of the equipment as possible. Since any equipment procured by the Services must pass very rigid mechanical and electrical specifications, it was found desirable at the Laboratory to build models in accordance with the latest production design technique. An effort was made to carry in the Laboratory's stock room only components which were known to be acceptable in production equipments. Incorporated in Laboratory prototypes, for example, were the special moisture-proof potted transformers called for by the Service specifications. In this way, it was possible to make the manufacturer's job easier by cutting down time required for redesigning the Laboratory model. In the early days, some of the Laboratory models required considerable treatment of this sort; however, as time went on this particular source of delay was considerably reduced.

An important step in this chain was the RRL Test Laboratory, an organization operating independently of the regular development groups, whose sole job was to carry out an impartial mechanical and electrical test of each Laboratory prototype equipment as it came along, in order to determine its performance and its suitability as a prototype for submission to a manufacturer. By thoroughly measuring and checking the performance of each unit, later differences of opinion as to acceptable performance could be avoided. Moreover, by standardizing measuring techniques, a great service was rendered both to the Services and to the manufacturers in making closer control of production tolerances possible. Addition of the Test Laboratory very greatly improved the quality of the models produced by RRL by educating RRL development engineers, and the extra time spent in checking performance in Cambridge was more than compensated for by reduced manufacturing difficulties and delays.

As mentioned previously, RRL endeavored to speed up regular production by picking manufacturers for model subcontracts who would be likely to receive eventual full-size production orders. In addition to maintaining close technical liaison with each development, the Laboratory also incidentally monitored the number of equipments produced, through personal contacts made by Transition representatives at the various manufacturing plants. On the basis of both formal and informal production information, regular bi-monthly production "Summary Charts" were prepared for the purpose of keeping those concerned with the RCM program abreast of new developments in the manufacturing situation. It was found to be particularly true in the case of RCM, that intelligent planning for the operational use of the equipment was absolutely dependent on a knowledge of the availability, or probable availability, of the various items involved. In planning a Carpet barrage jamming program, for example, it was necessary to know how many transmitters were going to be available for the purpose intended, since the method of operation was greatly dependent upon this number. The availability of many jammers makes possible their use in a barrage; if only a small quantity can be counted upon, a more economical method of their use (such as spot jamming) must be found.

Business

Radio Research Laboratory, with its 810 direct employees and 133 affiliated personnel, a payroll of \$2,550,000 yearly, peak expenditures at the rate of \$7,000,000 yearly, field stations in Bedford, Florida, and England, and technical representatives throughout the war theaters, was a substantial business enterprise and required a large business staff. At the peak of laboratory growth in September 1944, there were 223 people in the groups reporting to Mr. N. P. Breed, Business Manager, a ratio of approximately one to four to total personnel and approximately one to one to productive research workers.

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Broadly speaking, the Business Office was delegated responsibility to the Director for performance of all clauses in the OSRD Contract except the subject work clause, and, in addition, endeavored to provide the research groups with adequate personnel, space, facilities, equipment, materials, and services for the most efficient utilization of Research Associate time. Every effort was made to minimize organizational red tape and waste of time by the research staff on problems of securing articles or services needed for their work. For example, an oral request only was necessary for the procurement of some needed item in a research group. The business staff would make a catalogue selection, requisition, purchase, receive, and inspect the item, and deliver it to the requester without further attention on his part. Similarly, automobiles and drivers were held available for field trips, aircraft for flight testing were manned and equipped as needed, and crews were on hand to make any type of experimental installation. Travelers could expect to receive, just before starting a trip, an envelope containing all needed tickets and hotel reservations and sufficient cash for the probable trip duration. There can be no question but that these services greatly increased over-all efficiency by minimizing delays and interruptions in the technical work.

From March, 1942 to April, 1944, the period of active recruiting of technical manpower, the Personnel Department reported directly to the Director and was concerned primarily with the search for manpower to meet internal demands. The laboratory was late in starting as a war activity and thus was unable to acquire and maintain a proper ratio of experienced supervisors in proportion to the younger and less experienced groups necessarily hired. In addition to a good deal of informal internal training, formal programs were instituted for the training of a group of physical chemists at Harvard and M.I.T. and for the training of groups of girl machinists at the Worcester Trade School. In compliance with the wishes of OSRD and Harvard, no hiring was done in the draft vulnerable age group, except for fully qualified scientific personnel, with a resulting high proportion of women and older men being hired.

With the transfer of Personnel to the Business Office in April, 1944, attention was given to pressing problems of salary revisions, routine personnel administration, Selective Service problems, and employee morale. An employees' Social Committee was sponsored and financed, a series of motion pictures and talks were provided to spread knowledge of the laboratory's activities among the workers, a First Aid Room was established with a registered nurse in attendance, a complete job and salary survey of the laboratory was made and obvious inequities corrected. Selective Service continued to be a bugaboo throughout the history of the laboratory and absorbed much time and energy from the program. At times it seemed as if all the work that had been done and all the excellent leadership of the Scientific Personnel Office of OSRD, had been in vain. Actually, no employee having technical ability of high order was drafted, but pressure became so great in May, 1944 that nine young Research Associates were scheduled for overseas missions, by agreement with the State Director of Selective Service, to avoid being drafted. Personnel activity was headed by Mr. W. T. Harrison until April, 1944 and by Dr. Gordon Sutherland thereafter until the close of the laboratory.

Procurement, under the direction of Mr. C. L. Cole, was organized to handle all phases of obtaining and distributing equipment and supplies for the research groups, and included the functions of Purchasing, Subcontracting, Expediting, Priorities, Receiving and Shipping, and Stockroom. To provide a coordinating medium for preparing requisitions and offering technical advice on components, a Planning Department functioned independently of the Business group, but performed essentially business functions. This group also prepared specifications for all outside

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411-299

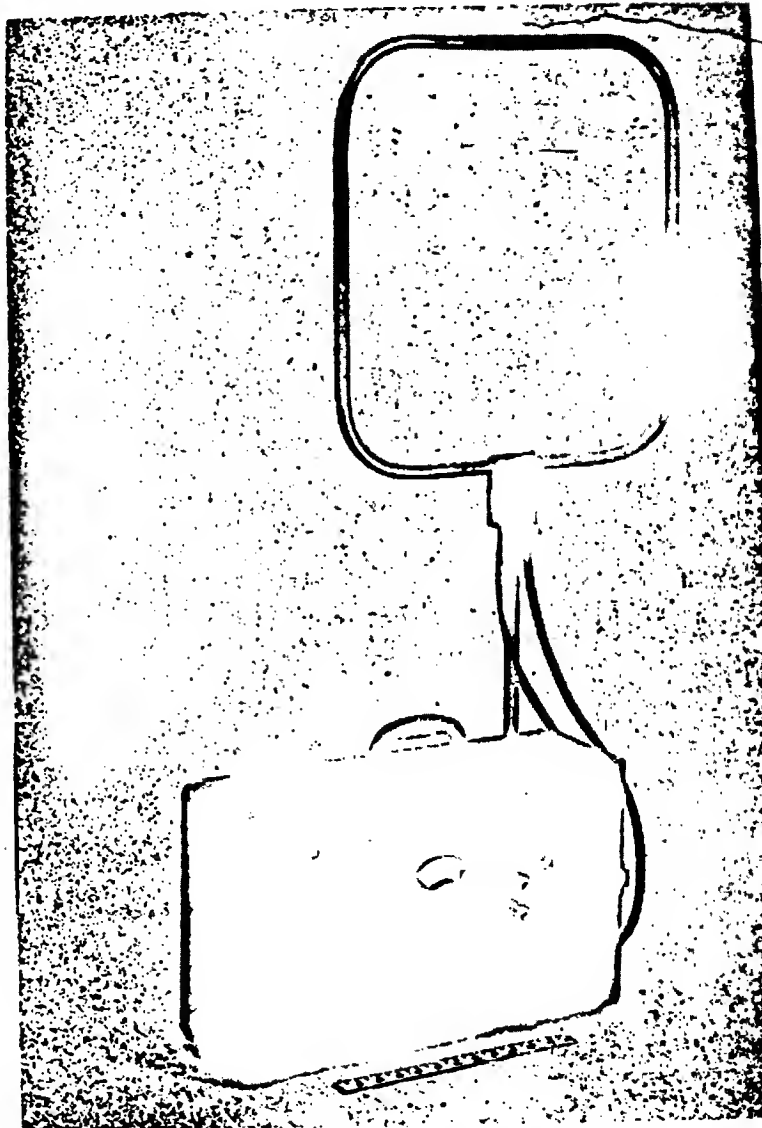


Figure 49. P525A jamming signal generator - for training use

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411-299



Figure 50. Under side of single dial tuning unit,
showing variable cam

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411-299

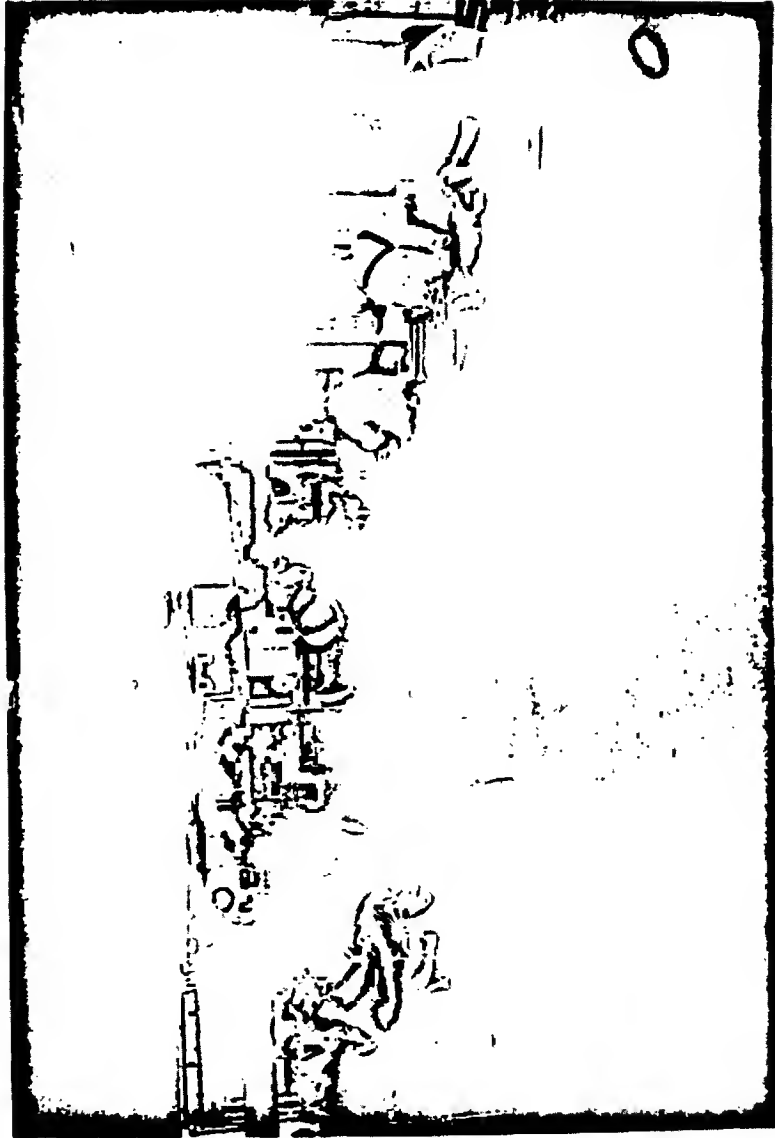


Figure 51. A portion of the Machine Shop

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shop work and controlled the scheduling of all Shop and model procurement work. Starting from nothing, these groups planned, purchased, and distributed the thousands of items required for a large research laboratory and its field stations and for the model and crash program procurement that followed. By June 30, 1944 the main stockroom alone contained 10,389 different stock items valued at \$483,838.

Later, when the laboratory was well established and had acquired a reputation, procurement difficulties eased, but in the beginning WPB, ANMB, ANCPEA, CMP and the other alphabetical control agencies seemed designed for the purpose of preventing RRL from obtaining the materials it needed to exist. From a precedence rating of D-250 the laboratory was promoted to A-241 and finally to A-1 on several critical equipments. To illustrate the variety of problems encountered, Procurement was called on one day for one each of every receiving tube type manufactured since the DeForest Audion (for noise study purposes) and shortly thereafter for all supplies and equipment needed fully to equip a one hundred man laboratory in England. The latter job was accomplished in one month by buying teams which went to New York, Chicago, Philadelphia, and Boston and coordinated their purchases each night by telephone until the required 10,000 items, many in critically short supply, were bought, packed, and shipped.

With the cooperation of Transition a highly efficient system of subcontracting was worked out and used for 173 different contracts with manufacturers throughout the country covering procurement of RCM equipments valued in excess of \$1,750,000. In general, the subcontract procedure called for construction of a prototype at cost with full technical and supply assistance from RRL, plus a supply contract for 20 to 25 models to be designed and priced from the prototype experience. Early issuance of a Letter of Intent for the supply contract permitted advance procurement of critical parts and elimination of all delays not inherent to the manufacturing process or the technical problems of the equipment concerned.

A Facilities division was organized to provide the building space, equipment, and services required for laboratory operations. In addition to 30,000 sq. ft. partitioned off in the North Wing of the Biological Laboratories Building for use by RRL, additional space to a final total of 104,000 sq. ft. was obtained in Cambridge by construction of temporary buildings and equipped with supplies for water, gas, compressed air, light, power, etc. While space available occasionally got below 100 sq. ft. per person over-all, it was found that this overcrowding was inefficient and hampered needed internal flexibility. In all planning a minimum allowance of 150 sq. ft. per person over-all was considered essential. Space was altered only to be realtered to meet technical needs, and crews of carpenters, electricians, and plumbers were constantly at work within the buildings, in addition to regular maintenance, cleaning, and utility crews. This division also supervised the Travel Department (\$10,000 per month travel volume), a Messenger Department, Traffic Department (11 beachwagons and 2 trucks), an Instrument Department, a Wood and Plastics Shop, and a Cafeteria.

Other "business" functions were Accounting (including some cost accounting required for pricing Lend-Lease and crash program transfers), budget preparation and control, security regulation education and enforcement and the maintenance of a guard force, coordination of business activities in England and Florida, and administration of an airport hangar operation. A Publishing Department, which started in a small way, increased tremendously during the final publication program as illustrators, letterers, spotters, proofreaders, typists, photographers, collators, multilith operators, and others brought the total number of printed pages produced to two million and sixty thousand.

Radio Research Laboratory expenditures will ultimately total just under \$15,000,000, not including \$710,000 expended by American British Laboratory of Division 15 in England. The breakdown of these expenditures for the period from March 21, 1942 through February 28, 1946 is as follows:

Classification	Expenditures	%
Salaries & Wages	\$6,293,000	44.0
Equipment	1,157,000	8.1
Supplies	3,104,000	21.7
Telephone & Telegraph	207,000	1.4
Postage, Express, and Freight	164,000	1.2
Travel	439,000	3.1
Heat, Light, and Power	77,000	0.5
Improvements and Alterations	170,000	1.2
New Construction	501,000	3.5
RCM Equipment Subcontracts	1,618,000	11.3
Miscellaneous	45,000	0.3
Overhead	531,000	3.7
TOTAL	\$14,306,000	100.0%

Invention Disclosure

In view of Harvard's expressed policy that no patent benefits from its Government financed war work should inure to it or its employees, Contract OEMsr-411 was written with the "short-form" OSRD patent clause and all employees under the contract executed agreements to disclose all inventions made during their employment and generally to assist Harvard in compliance with its patent obligations. For a number of reasons, including security requirements, the OSRD later arranged with the Navy Department to take responsibility for disclosures under and in compliance with this clause and implementing agreements to this effect were executed and carried out.

In order not to divert energy from critically urgent programs or to develop too early a "patent conscious" attitude, no patent work was done until the summer of 1943, when one man was assigned to the task and the beginning of a disclosure file started. Later in the year, a larger group was organized under Mr. C. W. Oliphant and continued by Mr. Elton Barrett when the former was assigned to a Technical Observer Mission in the Pacific. Mr. Barrett possessed the unusual advantages of technical training, experience as a Research Associate and Project Leader, and some legal training, and the work was completed satisfactorily under his direction.

In order to ascertain what inventions or discoveries should be reported, periodic interviews were held with all research personnel and all Laboratory Notebooks, reports, memoranda, and models reviewed regularly. As an extra precaution all personnel, both technical and non-technical, were personally interviewed by members of the patent group prior to termination. A broad disclosure policy was followed as insurance of disclosure completeness and nice questions of patentability or anticipation were left for the review of the Navy Department legal staff. A total of 606 invention disclosures were made under the contract and one of its subcontracts and it now appears that the Navy Department will prepare patent applications on a large percentage of the disclosures.

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411-299

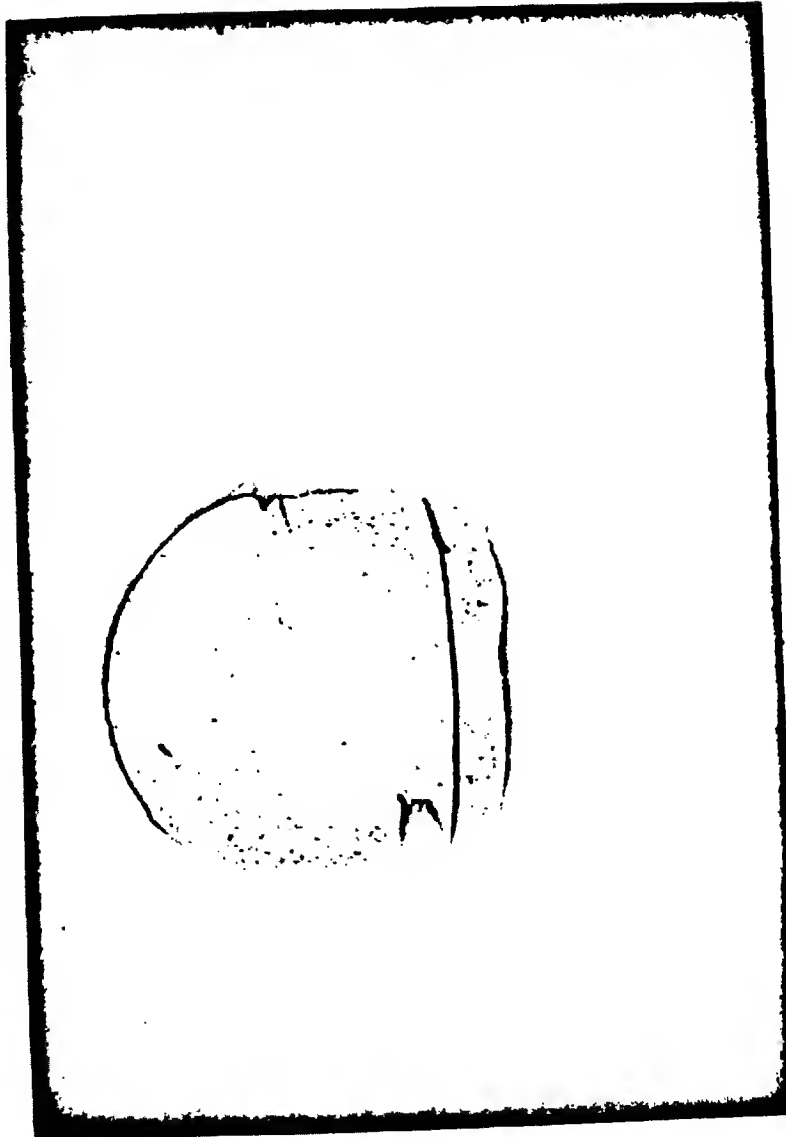


Figure 63. Molding a "blister" in the Wood Shop

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411-299



Figure 53. A corner of RRL's Test Laboratory

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Laboratory Shops

During the peak of its activities, the Laboratory employed approximately 97 machinists, virtually all of whom were assigned to the Laboratory's central machine shop. Work was carried on during day and night shifts.

The number of draftsmen employed was approximately 50, or one to every four research associates. The majority carried out their work at a centrally located drafting room; however, for the sake of efficiency some were assigned to individual development groups.

In addition to the main machine and metal shop, the Laboratory maintained a variety of smaller special shops. The Wood and Plastics Shop specialized in making the plastic "Blisters" used to house, protect, and streamline antennas mounted aboard both aircraft and ships; much time was saved by having this facility at the Laboratory. Since all RRL prototype models were built in accordance with Service specifications, using sealed condensers, impregnated transformers, etc., it was found necessary to set up a separate Transformer Shop in order to assure a prompt supply of specially designed and properly encased transformers. The availability of this shop also greatly aided in the development of the unusually wide-band transformers used in some of the Laboratory's later developments, such as the AN/APQ-20 and the XMBT (Elephant) jammer.

There was also a special Paint and Plating Shop, very necessary in the early days on account of the special metallic plating needed in connection with such items as the "Rollo" variable inductances used in many of the jamming transmitters.

In order to record the Laboratory's activities as well as to prepare photographs for the many reports, a Photographic Department numbering some four to five persons was set up. In addition to this group, which specialized in still photography, it was found that the need for training and indoctrination in connection with the rapidly changing countermeasures program, made it desirable for the Laboratory also to have a separate Motion Picture Department, numbering some five persons. This group recorded many transitory phenomena too complicated for still photography, and turned out many test, demonstration, and sample training films.

The Test and Standards Laboratory, which had responsibility for checking each Laboratory prototype before its submission to a manufacturer, was staffed with some 16 persons of which 10 were research associates. A total of over 300 test reports of various kinds were published by this group; these reports varying in subject matter all the way from such things as the mechanical specifications of cable connectors, to the detailed electrical characteristics of microwave jamming transmitters. This Laboratory was directly responsible to the Executive Engineer, and provided means for obtaining objective evaluation of equipment developed at RRL. The Test Laboratory was provided with facilities for making both electrical and mechanical tests, including vibration, temperature and pressure. Its extensive use resulted in the apparatus design groups developing their design techniques to the point where first models of new equipment would always pass service tests without trouble by the time RRL was ready to release them.

The internal group, which had the responsibility for making up a limited number of samples of each of the Laboratory's developments, was known as Group Y. At its peak, this model shop, assembly, and test group numbered well over 50 persons, of which roughly 17 were research associates.

CONFIDENTIAL

It had its own test laboratory which tested Group Y production, and also models delivered by outside contractors.

Field Testing

Countermeasures development work requires relatively elaborate field testing facilities, since it is necessary to test new developments against captured enemy radars or equivalents thereof, as well as to test them under conditions as nearly "operational" as possible.

In August, 1942, flight test facilities were set up in a hangar at the East Boston Airport. Three planes were permanently assigned to the Laboratory by the Army, and arrangements were made with the Navy to supply aircraft on request. The limited ground space available, however, prevented the setting up of more than one radar at the airport, and reliance had to be placed on the radars operated by the Anti-Jamming Division on the roof of the Radio Research Laboratory itself - a site which was far from ideal. When, in May, 1944, the RRL testing facilities were moved to a hangar at the Bedford Army Airbase (about ten miles from Harvard University) a much more satisfactory arrangement resulted. At this excellent location two ground radars (an SCR545 and an SCR648) were installed, and the Laboratory's testing program greatly expedited. By the end of the war, some eight aircraft were permanently assigned to RRL; these included a B-29, a B-24, and two B-17's. The Laboratory maintained a staff of some ten persons at Bedford. Laboratory aircraft flew nearly 900 hours between May, 1944, and the end of the war. Important studies of the effectiveness of the AN/APQ-20 centimeter jammer against the SCR545 radar were made at Bedford.

In June, 1943, the Army Air Forces set up a countermeasures testing station at Auxiliary Field #9 (Florosa Field) of Eglin Field, Florida - headquarters of the Army Air Force Proving Ground Command. Division 15 was invited to share in the facilities offered by Florosa Field, and a small field laboratory staffed by RRL was set up in a building shared by a field branch of the army's Aircraft Radio Laboratory. RRL's staff at Florosa included a director, a business manager, three to six research associates, several technicians, and others.

The Army Air Forces made available many aircraft for tests at Florosa. In addition, there were installed at Florosa a large number of radar equipments (operated by Army crews) ranging from a captured Japanese 100 Mc set, to the latest in 10 Cm harbor defense equipment. These facilities proved very valuable for those extended field tests which benefited from the inclusion of large numbers of aircraft and large numbers of radars; for example, studies of Window and Rope. Other important work included tests of Carpet and Window against a captured German Wurzburg, when 12- and 18-plane formations were involved.

However, in view of Florosa Field's remoteness from RRL and its relative inaccessibility, it was found to be more economical of research manpower to conduct as many small-scale tests as possible close at home.

Division 15 and Service Liaison Offices

It is not strictly within the scope of this report to describe or evaluate the liaison offices which were maintained at the Cambridge laboratory by Division 15-NDRC, the Army Air Forces, the Signal Corps, or the Navy, but it would be unfair to omit mention of these groups or to fail to give credit for their substantial assistance to the program. As activities increased in tempo, it became apparent that ad-

CONFIDENTIAL

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6-16

ditional facilities for expedited action on the part of these agencies was necessary if serious delays in the program were to be prevented.

The Service Liaison offices, Navy, Signal Corps, and Air Force, all originally stemmed from existing groups at Radiation Laboratory, M.I.T. However, in the order named, all established independent offices at the Laboratory under accredited liaison officers, and all assisted greatly in promoting the Laboratory program and close cooperation between it and the respective Service laboratories, planning groups, and field forces.

NDRC-Division 15 also recognized the necessity for maintaining an accredited government representative in Cambridge. In September 1943, Mr. D. B. Harris was assigned to Radio Research Laboratory as Technical Aide with full delegated authority to act for the Contracting Officer in virtually all matters affecting the interests of the Government. In addition, Mr. Harris was charged with the responsibility of coordinating the activities of the Laboratory with those of the other Contractors of Division 15 through the Division 15 Committee. As activity increased, it became necessary to increase the staff of the Division 15 Cambridge office from its 3 to an ultimate group of 10, including a second Technical Aide, Mr. H. W. Albrecht, who joined the organization in February, 1944.

Demobilization

After the OSRD demobilization flurry in October and November of 1944, RRL followed a policy of scrutinizing all new project requests and only accepting those which (1) could not be properly handled by other agencies, (2) were of such character as to be of obvious importance to the war, and (3) could be completed with relative rapidity. As an example, the largest commitment undertaken under this policy was the Elephant project (accepted in February, 1945, with a completion date of August, 1945), in connection with which RRL was in a position to make a unique contribution.

As a result of this policy, RRL was in a very fluid condition when the European war ended in May, 1945, with virtually no commitments that could not be met by the end of 1945. After V-E Day but before V-J Day, plans were made for a further shift in emphasis away from the development of new devices and more in the direction of making effective use of existing equipments against the Japanese. A Pacific Applications Committee (whose assignment was the detailed study of the Pacific RCM) was set up in May. The Laboratory's Field Division was at the same time expanded and was instructed in June to devote the next sixty days to doing everything possible to increase the usefulness of equipments already in the Pacific. (That is, to carry out studies of the best use of antennas, jamming power requirements, installation problems, etc.)

Longer-range plans involved a greater expansion of U. S. and overseas field work. (Dyer, after his return from ABL-15, was to be in charge of this phase.) The field group was expected by January 1, 1946, to represent at least half of the technical activity of RRL. Research and development work was expected to be greatly reduced by transfer of personnel to field problems. It was further expected that, beginning in August, there would be a slow reduction in number of technical personnel owing to their return to former jobs, etc. Thus the Laboratory was well prepared for a sudden cessation of the war.

An excellent example of the effectiveness of the Laboratory's liaison with the Services and of the value of the liaison activities was provided by the laboratory's demobilization program put into effect immediately after V-J Day.

CONFIDENTIAL

When the end of the war was obviously approaching, the Laboratory's Project Committee reviewed all projects in hand and divided them up into three categories: those whose nearness to completion or whose post-war merit was sufficient to warrant their being carried on to a conclusion (provided this could be achieved no later than November 1, 1945); those whose importance was such that they should be carried on to a point at which the value of past research would be preserved; and those of no further possible usefulness which should be dropped. Classification of the work into these categories was facilitated by the fact that by the end of the Japanese war, the Laboratory was working on very few long-term research projects. By that time, the emphasis of the program had been shifted almost entirely to such short-term items as field testing, operation analysis, and minor modifications of existing equipments, i.e., to activities of immediate operational use.

The Project Committee's proposed disposition of the Laboratory's projects was referred on August 18 to the various interested services, and a meeting was then held at RRL on August 23 at which the Laboratory's proposals were reviewed in detail by the Services. The Laboratory's recommendations were adopted with very minor changes. The fact that the Laboratory's proposal had been so close to the Services' own wishes is good evidence of the close contact and mutual understanding which existed between the Laboratory and the Army and Navy agencies with which it did business. In accordance with this agreement, a certain proportion of the Laboratory's projects were transferred in their entirety to Service research agencies such as the Naval Research Laboratory and the Aircraft Radio Laboratory. The "transfer" of projects here means both the transfer of all equipment prototypes, etc., and the provision of complete final reports outlining all work done at RRL.

Although many Laboratory prototype equipments were transferred to the Services along with specific research projects, a considerable number of models, manufacturers' samples, etc., still remained on hand. These were offered on August 14, to the various interested branches of the Services in a systematic way, and the entire lot - some 250 items - was thus disposed of piecemeal.

The physical plant of RRL (office furniture, machine tools, work shop equipment, etc.) was transferred intact in accordance with a unique arrangement concluded with the Office of Research and Invention of the Navy Department. Whereas other NDRC Laboratories had been liquidated either through the Surplus War Properties Administration, or through Army and Navy committees which selected more or less at random those items in which they were interested, the facilities of RRL were turned over as a unit to the newly organized Airborne Radio Division of the Naval Research Laboratory. This disposition was eminently satisfactory to both parties concerned; Harvard University was thus able to transfer the physical plant of RRL as a unit, and the Naval Research Laboratory acquired complete Laboratory facilities to serve as the nucleus of their new research organization.

By December 15, 1945, all RRL projects equipment, models and prototypes had been turned over to the Services, and the transfer of the machine tools, office furniture, radio component stocks, etc., was getting under way.

CONFIDENTIAL

VII. A BRIEF SUMMARY OF THE OPERATIONAL USE OF RCM EQUIPMENT IN WORLD WAR II

Introduction

The following section is intended to give an idea of the general types of tactical situations in which radar countermeasures were found to be of operational significance in the war. An attempt will be made to review these situations briefly; to indicate their relative importance (when possible), and to give some idea of the number of countermeasures equipments involved.

No attempt will be made to give technical details either of the operations themselves or of the RCM gear used. Full information of this sort is available from other sources.

I. European Theater

The first exclusively United States operation in this theater was, of course, the North African invasion. Not long after our troops had established themselves in North Africa, concern was felt by the Theater Commander over the enemy radar defenses of Sicily and Italy, which were found to be a serious threat both to our aircraft and to our next amphibious operation itself. It was decided that the Army Air Forces would undertake a program of radar scouting in order to supplement the work being done by a British investigational group (192 Squadron), which had already been operating in the Mediterranean area. Cabled requests to the United States for the necessary equipment with which to begin this work led to the preparation and dispatch to the theater of a specially equipped B-17 radar search aircraft given the descriptive code name of "Ferret." This plane carried a number of laboratory prototype equipments supplied by RRL, among them improved search receiver tuning units, a homing-type direction finder, and a device to warn of the approach of enemy radar-equipped aircraft (Zero Catcher). Accompanying this first Ferret expedition to North Africa as technical observer, was a senior RRL engineer. Other technical observers from RRL followed later.

This plane was the first of a series of Ferrets sent to the Mediterranean Theater which did an important job of locating and pinpointing enemy radar dotting the Northern shores of the Mediterranean.

In addition to the German early-warning and coast-watching radars, many antiaircraft gun-laying equipments were known to be in operation in this theater. These were a menace to our heavy bomber formations. Just prior to the invasion of Sicily, in response to another theater request, 35 B-17's were fitted out with Carpet and Mandrel jammers on a high priority basis in the United States and rushed to the Mediterranean theater. (Much of the final checking and testing of these installations was done at RRL's field station at Florosa.) Only four of the planes, however, arrived in time to take part in the invasion; nevertheless, this was the first use of Carpets against the German "Wurzburg" anti-aircraft radars.

The Navy's first operational use of jamming equipment came during the landings at Salerno. In order to protect our vulnerable landing craft during this operation, a number of "Rug" (AN/APQ-2) jammers were rushed by air direct from the factory to the Mediterranean theater, where they were installed in record time and used against the German coast-watching radars with good success. These

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411-299

"Rugs" were the very first to come off the production lines; RRL assisted materially in their quick preparation for this job by stationing an engineer at the factory in order to check the performance of each set, see that adequate antennas were supplied, etc.

Meanwhile, the 8th Air Force in England was beginning to expand the scale of its operations, and the problem presented by the German anti-aircraft radars was being given thought. As a result of tests carried out in the spring of 1943, it was definitely established that the Germans were using radar against our daylight missions. A model-shop-produced Carpet, one of a small number made up by RRL in advance of the regular production, was tested in a B-17 by an RRL engineer attached to a British countermeasures laboratory, and the jammer was shown to be effective against a British radar similar to the German Wurzburg. This was followed by an urgent request to the United States for a trial quantity of Carpets. Flown to the theater by air and installed under the supervision of an RRL engineer stationed in England, sixty-eight of these equipments saw service for the first time in October, 1943, with striking success; flak losses in the Carpet-equipped groups during the first raid to Bremen were cut in half. The Theater Headquarters immediately placed a requirement that every bomber earmarked for the 8th Air Force be equipped with Carpet.

The British had begun to use Window against the German Wurzburg radars in July, 1943, with excellent results. Although large, daylight formations are more difficult to protect with Window than planes operating singly and at night, the 8th Air Force began the use of this countermeasure in December 1943, shortly after "blind" bombing was begun. Window found wide acceptance in the Air Force; by January, 1944 for example, special chutes for the dispensing of Window had been widely installed, although it was always possible to eject the bundles from the waist gunners' position. The Window used actually consisted of several different varieties; a good share was British flat Chaff, but a substantial portion was Window made in Britain on RRL-designed cutting machines which had been crash produced under Laboratory supervision for the British. These machines had been diverted from the Signal Corps on the understanding that Window produced by them would be made available to the U. S. Air Forces in England. The "bent" chaff made with these machines was far lighter and more satisfactory than that used by the British on their first Window raid on Hamburg.

Small shipments of Carpets continued to arrive in England during the early part of 1944. However, during this period, the 8th Air Force was rapidly growing in strength, and the number of airplanes on hand always greatly exceeded the number of Carpets available for installation. The supply situation was such that in the period between the introduction of Carpets and approximately October, 1944, an average of only 9 per cent of the Air Force was equipped with jamming transmitters.

However, there was no shortage of Window during this period, and the enthusiasm for this countermeasure grew steadily. Through the efforts of RRL Window experts sent to England for the purpose, training in the use of this countermeasure was greatly improved; educational pamphlets were issued, and a much better understanding of the possibilities of Window resulted. When, as a consequence, the requirements for Window increased sharply during the summer of 1944 due to the introduction of improved tactics, new and better U. S. production Window, made possible by RRL-designed machines, was available to fill the demand.

In the late spring of 1944, U. S. blind bombing operations began to come into their own. From this time until the end of the war, roughly 40 per cent of the

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411-299

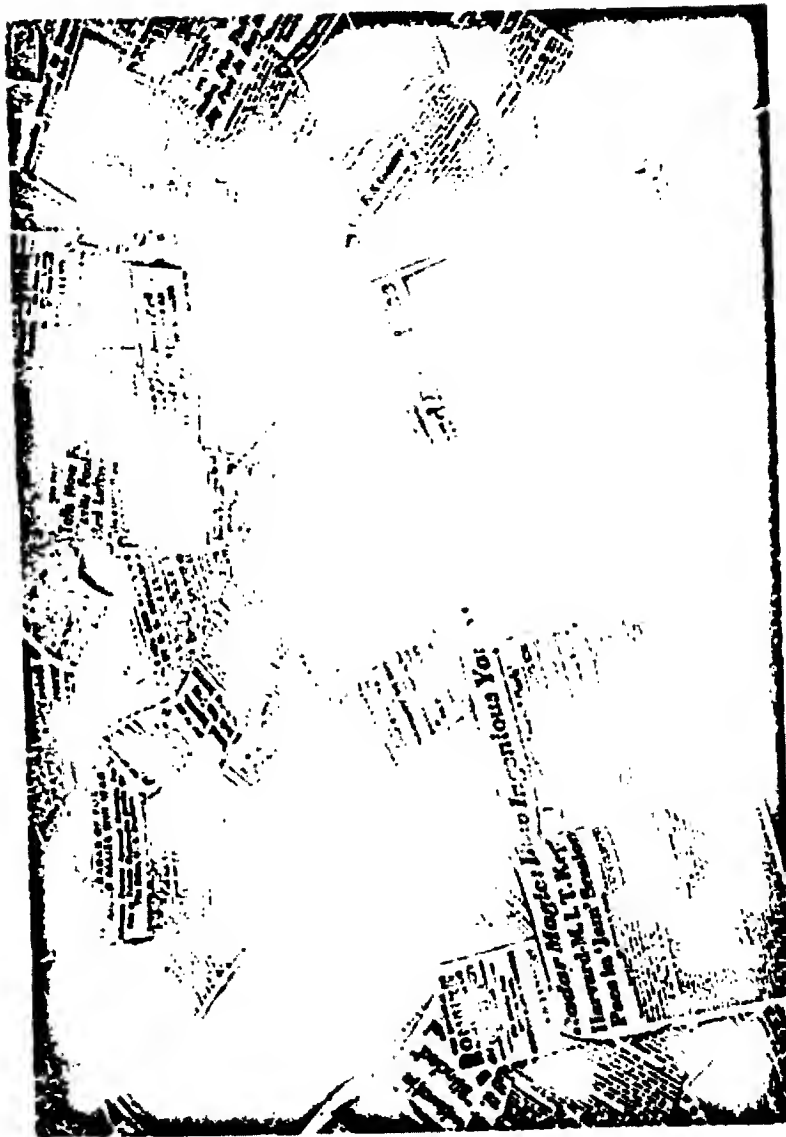


Figure 54. Press notices: clippings of articles based on the Laboratory's
press release

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411-299



Figure 55. Spot jamming installation in a B-24

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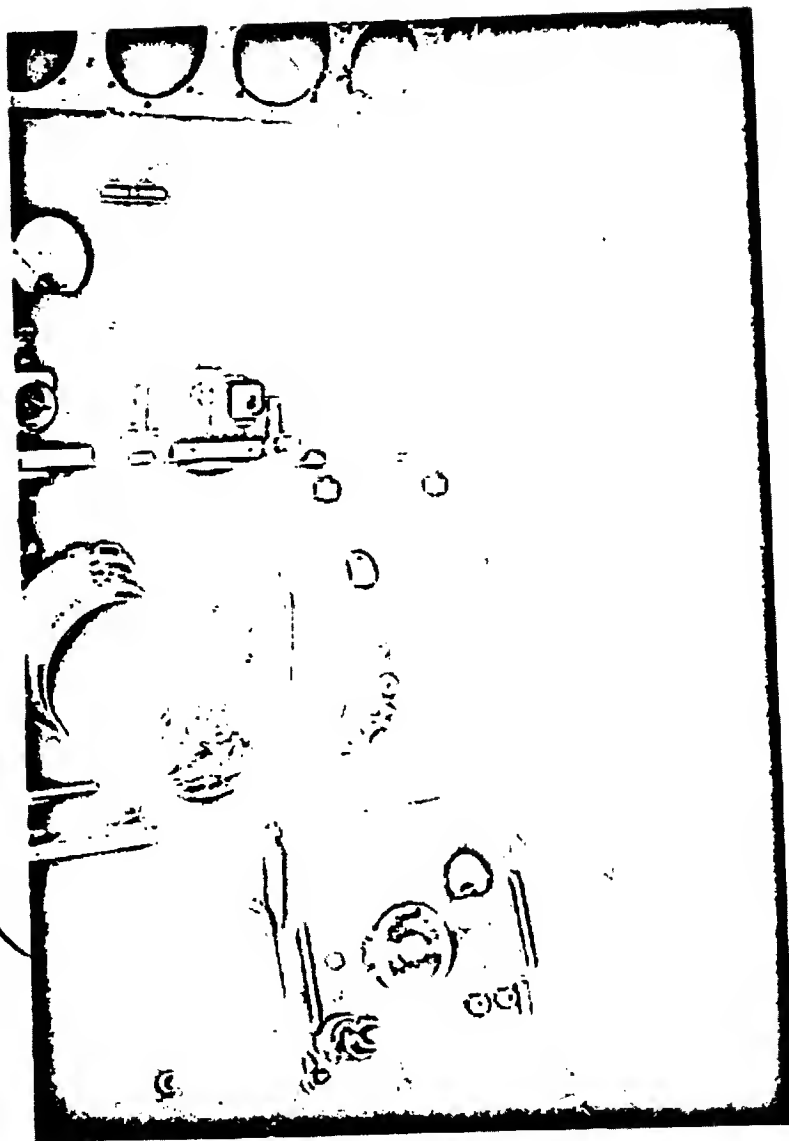


Figure 56. RCM installation in a PB4Y-Z search bomber

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strategic missions carried out by the heavy bombers were made over 8/10ths cloud cover or better. (The average number of days per month on which operations were possible rose from 9 in 1943 to 22 in 1944.) During this same time, German fighter opposition waned, and the Germans were left with no defense against blind raids save their anti-aircraft guns whose radars were being jammed. Under visual conditions, the Germans were no longer able to use smoke screens effectively, since our H₂X could "see" through the smoke, while our RCM prevented the enemy from aiming his guns through it. Blind bombing greatly increased the scale of the U. S. air attack, by making operations possible on days when planes would otherwise have been grounded. That the losses during these attacks were unusually low, can be directly attributed to the success of RCM.

Since by the late spring of 1944 large numbers of Carpet transmitters had been delivered by the manufacturers, RRL became deeply concerned by the continuing shortage of these equipments in the theaters. Led by Mr. A. E. Cullum, Jr., an Associate Director of the Laboratory, a thorough investigation of the U. S. Supply situation was carried out. As a result of this investigation, tremendous efforts were made to expedite the shipment of Carpets, and these transmitters, a thousand at a time, began to arrive in the European theater by September, 1944. They could not have been more welcome, because by that time, German fighter attacks were no longer a serious problem due to our bombing of German industry and due to the long-range fighter escort accompanying our heavy bombers. As fighter opposition decreased, losses and damage to flak became of greater and greater importance; moreover with flak their only defense against bombing missions, the Germans were doing everything in their power to make their already powerful anti-aircraft batteries more effective.

It is no wonder, therefore, that when the Carpet transmitters arrived in England, a tremendous effort was made by the operating forces to install these equipments in the shortest possible time. They were materially aided in this by engineers of ABL-15. These men helped the 8th Air Force train field installation teams; they assisted with mock-ups; helped break supply bottlenecks; set up operator training courses, and even went out to the many Groups receiving the new equipments in order to help with the installation and initial performance checking. To give some idea of the size of the undertaking, roughly 2000 AN/APT-2 equipments (Carpet I) and 4000 AN/APQ-9's (Carpet III) were sent to the European theater and there installed aboard operating bombers during the intervals between operations. (The 8th Air Force had some 3000 planes in all).

With the help of a staff member of ABL-15 on loan to the Operations Analysis Section, Headquarters 8th Air Force, plans for the most effective use of these equipments were worked out and modified as the changing conditions required. Changes in the Wurzburg frequency distribution were monitored by an 8th Air Force search program organized by ABL-15. By November 1944, over half the 8th Air Force was protected by electronic jamming installations in addition to Window. By December, over 80 per cent of the Air Force was protected by Carpet.

According to the final installation plan, two aircraft in each air squadron were given spot jamming installations of three transmitters and one receiver each, while all other aircraft (with the exception of a relatively small number of Pathfinders) were equipped with two barrage jamming transmitters apiece. Roughly 500 AN/APR-4 receivers, for spot jamming installations and investigational work, were shipped to the European theater in all.

CONFIDENTIAL

Thus, by the end of the war, every heavy bomber (Pathfinders excepted) attacking Germany was equipped with at least two, and in many cases three, jammers developed by the Radio Research Laboratory. In addition, each plane was assigned 720 units (about 100 lbs.) of Window to be used simultaneously with the jamming transmitters. (The total requirements for chaff had climbed, by this time, to the staggering figure of over 2,000 tons per month.) No objections were raised to the carrying of all this extra weight; in fact, the operating forces insisted on it!

In the Mediterranean theater, the story of the installation and use of Carpet and Window was roughly parallel to that of the 8th Air Force. Chaff was first used in February, 1944, and was enthusiastically received. The operating forces in that theater showed much ingenuity in the use of this countermeasure. Aided by PRL technical observers, who had accompanied the Mediterranean Air Forces since the days of the first Ferrets, such things as Window "bombs" - containing large amounts of Window, and dropped ahead of the main formations by fast fighters - were used with excellent success. In addition, by February, 1945, every group of the 15th Air Force had electronic RCM protection.

The results of the Carpet-Window attack on the Wurzburg radars were thoroughly assessed by ABL engineers who accompanied the first Intelligence teams to enter Germany after VE-day. Questioning German personnel from Luftwaffe generals to Wurzburg radar operators, they found that the morale of the entire flak organization had been affected by our countermeasures. Many believed that flak and radar were "outmoded" weapons. Nevertheless, by the end of the war, the extent of the German flak effort (which enjoyed the very highest priority) had truly been enormous. There were, in all, over 16,000 heavy guns, ranging in size from 88 mm to 105 mm, these were controlled by over 4000 sets of Wurzburg-type fire control radars and optical predicting equipments.

In order to save this enormous investment (estimated at over a billion dollars), the Germans devoted a tremendous effort to the reduction of the effectiveness of our countermeasures. Since the scale of our RCM effort was small at first, the Germans hoped to salvage their investment with palliatives, and developed and introduced in the field over thirteen anti-jamming attachments for their Wurzburg radars. At the end of the war more than nineteen anti-jamming proposals were under active development, yet none did the job! The Germans admitted that our combination of Window and noise jamming had been too much for them.

The number of scientists tied up by this tremendous effort was remarkable. According to Dr. Esau, who was head of all German high-frequency research at the end of the war, as high as 90 per cent of all available electronic engineers were tied up at one time on various phases of the anti-jamming program. As an average, about 50 per cent of the total, or about 4,000 persons, were assigned to this work. This is in sharp contrast with the perhaps 400 trained engineers (at RRL and elsewhere) who worked on countermeasures problems in the U. S.!

The Germans were prevented by our countermeasures from developing ten centimeter radar; they simply did not have enough engineers to exploit the new microwave techniques and at the same time carry on the anti-jamming work at the scale they did.

On the basis of interrogations carried out after VE-day (taken in the light of German records of Allied jamming, etc.), it is concluded that during the period from October, 1944, to the end of the war, the effectiveness of German anti-aircraft fire control radar was 25 per cent of normal. From this, and information on operations

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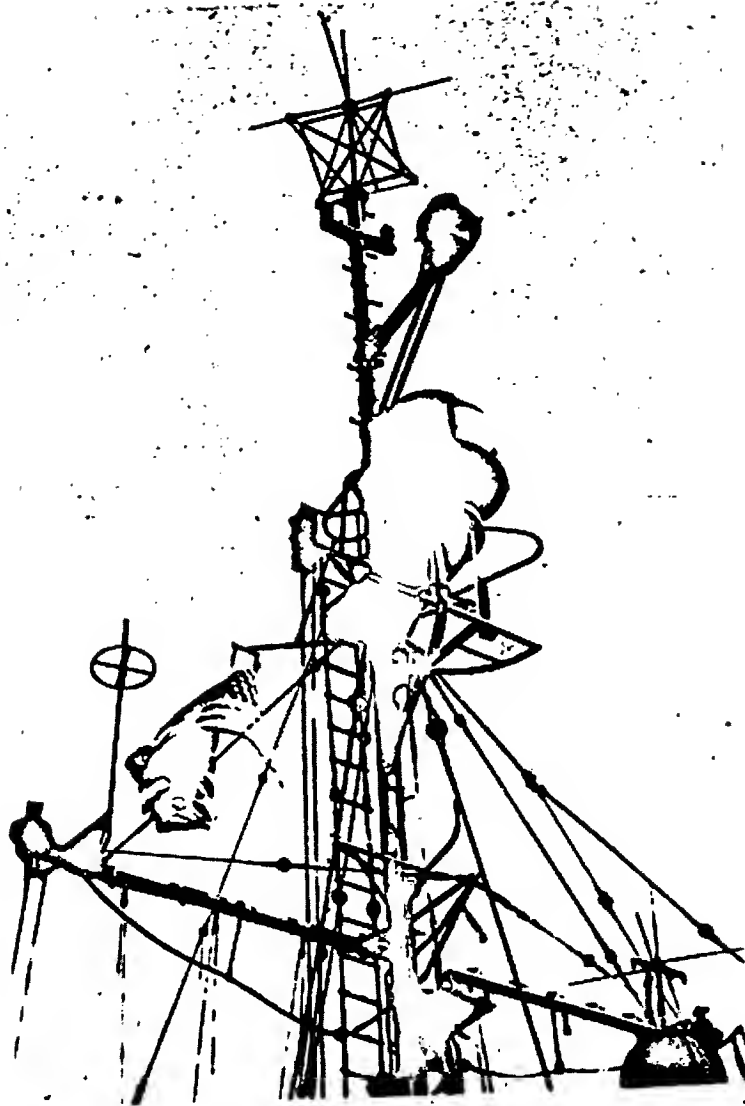


Figure 57. DBM spinner mounted above the radar on the foremast of a DE

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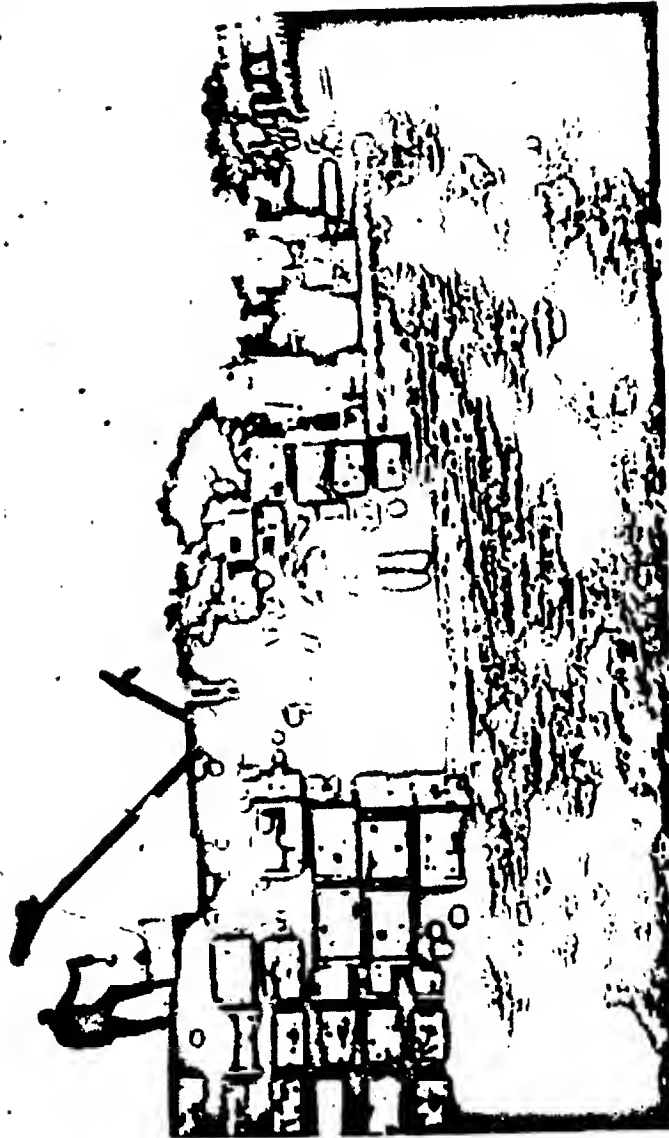


Figure 59. Carpet transmitters as they arrived at an installation depot in England

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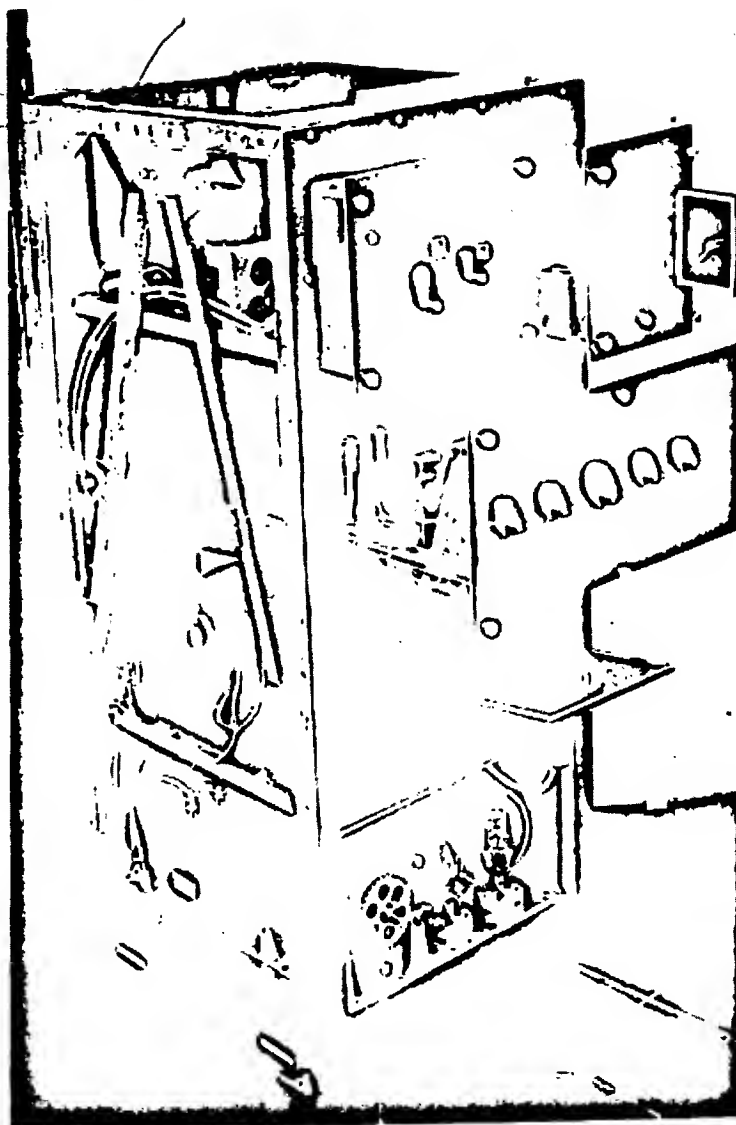


Figure 59. Laboratory prototype of the TDY transmitter

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supplied by the 8th Air Force, it is estimated that during this same period over 450 bombers (not to mention up to 4500 crew members) were saved by the timely application of Carpet and Window in the 8th Air Force alone!

Interrogations at Ploesti in Rumania (the second most heavily defended target in all Europe) revealed that over 25,000 rounds of heavy anti-aircraft fire were required by the Germans to shoot down one of our planes after the introduction of countermeasures.

The 9th Air Force, by way of an experiment to see if Carpets could be used in medium bombers, tried out a dozen or so in their B-26's. Very satisfactory spot jamming installations were made, with the help of ABL-15, and the practicability of the arrangement was proved. However, the lower flak losses suffered by the tactical air forces never raised the priority on RCM high enough to make electronic jamming installations worth the effort, although Window was used to good effect, and search programs were carried out in both the 9th and the 12th Air Forces. Because of the type of targets they attack, the altitude at which they operate, and the type of formations they fly, medium bombers are less vulnerable to flak.

In addition to the protection of heavy bombers during their missions, the 8th Air Force found another use for countermeasures gear as well. At one time, before the long-range fighter plane had been perfected, it was to the advantage of the 8th Air Force to avoid fighter interception as much as possible. One way to catch the German fighter defense system off balance was to deny the enemy radar observation of our planes while they were forming up over England before a raid. Accordingly, a jamming "screen", consisting of several planes each equipped with many jammers, was proposed. By flying over the channel coast, these planes could "hide" our forces while they assembled for a mission. Although screening planes were so equipped - with the help of ABL engineers - and the operation tried, the idea was eventually dropped because it became the policy of the 8th Air Force, after the introduction of long-range fighters, to allow the Germans as much warning of our approach as they desired. Screening missions were never attempted in the Mediterranean Theater because the geography of the area removed the possibility of achieving any kind of strategic surprise through countermeasures.

Virtually the only occasions for the use of RCM equipment by the U. S. Navy in the European theater, (aside from the landings at Salerno, Anzio, etc. during the early Mediterranean operations,) were the invasions of Normandy and Southern France. Of these two operations, Normandy represented the largest from the countermeasures point of view.

In anticipation of our invasion, the German radar defenses of Northern France, and the Channel Coast in particular, had been made extremely formidable. The enemy had installed radars of all kinds - Coast Watchers, early-warning Freyas, and even Wurzburgs which had been adapted for surface search and fire-control. No less than 12 different varieties of these basic equipments were to be found in the so-called "invasion belt"! There was an average of one radar for every one to one and one-half miles of coastline.

The invasion itself consisted of a main Naval attack force plus two diversionary forces which proceeded to the north and the south of the actual invasion site. In addition to these Naval activities, there were airborne troops to protect as well.

The enemy had to be denied, in so far as possible, any advance knowledge of the main landing points, as well as advance knowledge of the strength of the forces

involved. In addition, he had to be denied the ability to direct gunfire at our forces under "blind" conditions.

Prior to the invasion itself, the U. S. and British air forces carried out a tremendous aerial bombardment of German radar installations along the entire coast of Northern France. Some 5,000 tons of bombs and no less than 3500 rockets were expended in this effort. The attack undoubtedly put a fair percentage of the potentially dangerous German radar stations out of action. The remainder had to be knocked out by jamming or deception, or a combination of the two.

Both U. S. and British Navies decided to install a large number of unattended and manually-operated jammers aboard their ships and landing craft. The effectiveness of these equipments was established during a series of invasion rehearsals held at a testing site near Edinburgh in Scotland. Here, with the help of ABL-15 and other civilian engineers, both U. S. and British jamming equipments were tried out against captured German radars in representative Naval vessels. Civilian engineering assistance proved valuable at this juncture, because it was found that certain of the jamming transmitters interfered with other essential services when operated in close proximity to them, as during an invasion.

The American Navy, assisted by engineers from ABL-15, installed some 76 jammers (originally designed for airborne use) in landing craft. In addition, 10 high-power magnetron jammers (CXFR's) were installed on cruisers, battleships, troop carriers, etc. In addition to these strictly jamming installations, search installations (covering the complete spectrum up to 6,000 megacycles) were made aboard two cruisers. Since all of this work was carried out with the assistance of ABL-15, the number of equipments involved is known with some certainty. However, much additional equipment was installed by Navy RCM teams and other personnel; according to official information, a total of 262 vessels of all types received RCM equipment of some sort. A total of 55 warships were given this protection, and the Navy's countermeasures installation program alone tied up more than 50 officers and men for a period of seven weeks. Of the 88 jamming equipments installed under the supervision of ABL-15, 45 or roughly 50 per cent were equipments designed by RRL or designed with the direct assistance of RRL.

Of the many ships of the British Navy given RCM protection, a very large percentage were scheduled to receive American-built RCM gear. It was soon realized by the British, as well as by representatives of ABL-15, that there were by no means enough persons familiar with American equipment available in the British Isles to do this job. Additional help from the United States was urgently needed. This led to General Eisenhower's request to General Marshall for 16 U. S. engineers to assist the British Navy with the installation of U. S. jamming equipment. The 16 men arrived in record time; 13 of them were at once assigned to the installation work which took place in some ten widely separated ports, ranging in location from Exeter on the South Coast, to Scapa Flow in the Orkney Islands. In all, this group installed 264 RCM equipments, of which 90 per cent were designed by RRL. In thanking the Americans for their help after the invasion, the British stated that they could not possibly have done the work by themselves. According to Commander Robinson, the British naval officer in charge of the work, a total of 530 jamming equipments were installed in both Navies, of which roughly 400 were American-built.

In addition to jammers, both British and American Naval diversionary forces employed balloon-supported corner reflectors which increased the apparent "size" of these vessels when under radar observation. In addition, the Air Forces dropped

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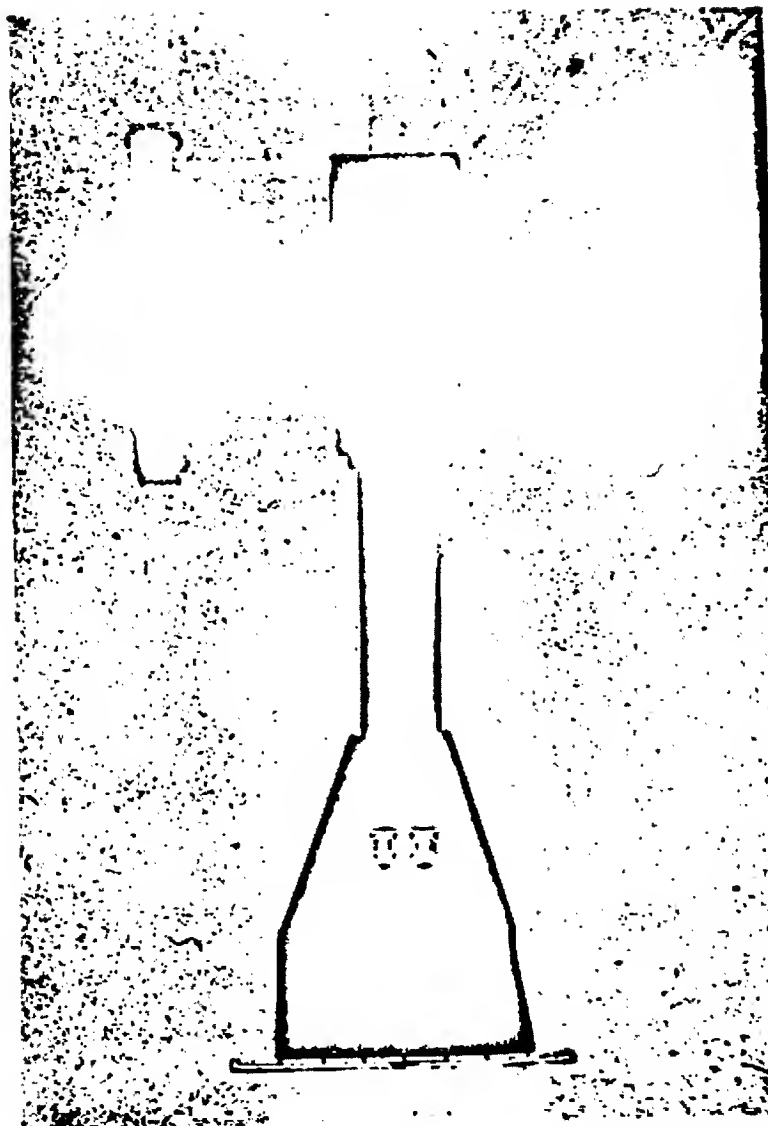


Figure 60. Wide-band dipole antenna developed for interim shipboard use

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Figure 61. The AN/APA-24 Direction Finder is provided with a line of interchangeable heads

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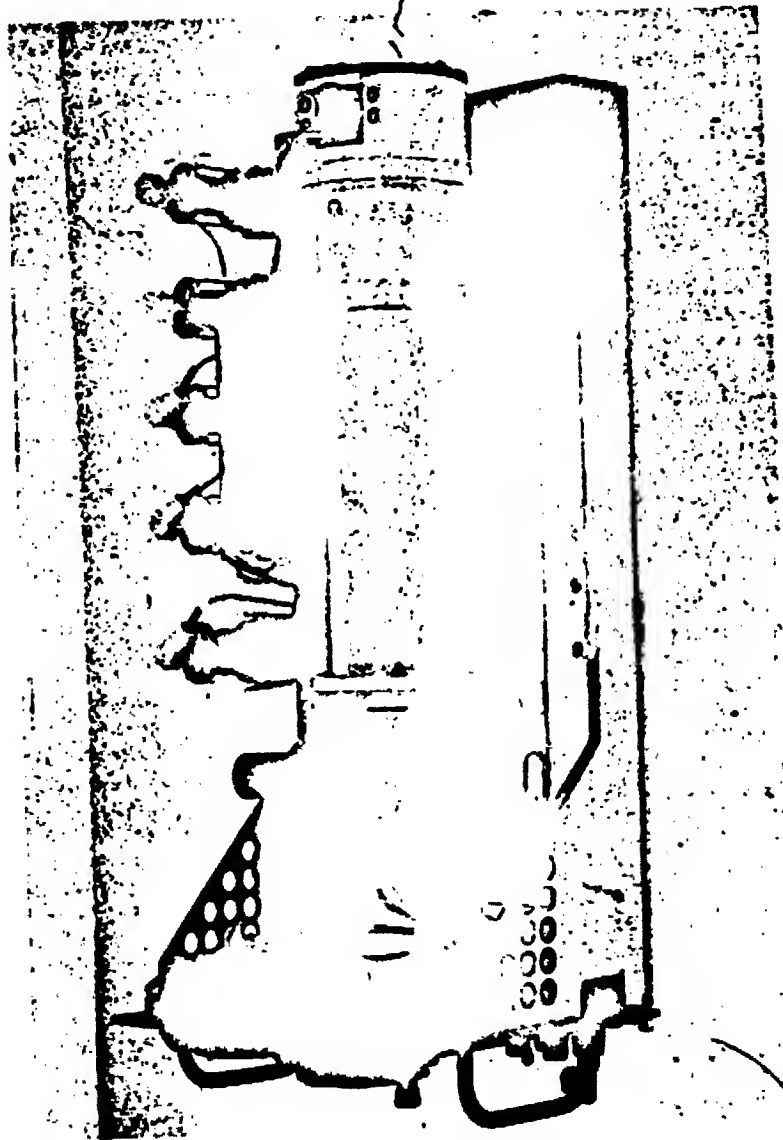


Figure 62. The AN/APT-9 lighthouse tube jammer

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large quantities of Window from low flying, circling aircraft over many of these ships, thus still further increasing their apparent "size."

German fighter opposition, a serious threat to our Airborne operations, was successfully diverted by the British during the night before D-Day. A small force of Window-laying aircraft, which flew across the Channel north of the invasion area, succeeded in giving the impression that a large bombing force was about to enter Germany at that point. Having drawn up the German fighters, these planes then jammed the German communications channels in order to still further disrupt the enemy fighter control system. Just prior to the actual airborne operations themselves, American aircraft carried out Window diversions intended to simulate a number of different airborne attacks in order to divide still further the German defenses. As a result, our airborne landings in the Normandy Peninsula were carried out with remarkably low losses - less than 1 per cent.

As nearly as can be determined, the RCM phase of the Normandy operation was a success. It is known that the German were led to believe that the invasion was taking place at a point further north than that at which it actually occurred. During a later interrogation, an enemy radar operator located at what became the Omaha beachhead asserted that he had not known what was approaching; he had merely been aware that something unusual was taking place. When one U. S. Cruiser, not equipped with jamming equipment, found itself subjected to uncomfortably accurate enemy fire, the officer in charge of the operation directed that ship to change places with another cruiser equipped with a jammer. As soon as the substitution had been made, the enemy gunfire became inaccurate and soon stopped altogether.

The invasion of Southern France followed the pattern of the Normandy operation. This time, however, the Air Forces' shooting up of enemy radar stations prior to the operation was begun too late to be effective, and the full burden of protecting the assault forces from enemy radar observation fell on the RCM equipment. Again, the invasion itself consisted of an assault force, plus two diversionary forces. According to one official source, 500 RCM equipments, including receivers, were installed aboard U. S. Naval vessels alone. It is known definitely that a total of 260 jamming transmitters were installed by both the British and American forces taking part in this operation; 80 by the British, and 180 by the Americans. The main assault force was allocated roughly 85 per cent of the available jamming equipment; the remainder were installed in the diversionary forces. These diversions were deliberately given incomplete jamming protection so that the enemy would be able to "see" the corner-reflector-equipped and Window-protected "spoof" ships approaching.

In the main forces, RCM equipment was installed on the following U. S. and British ships: 4 battleships, 2 transports, 12 cruisers, 15 destroyers, 24 mine sweepers, 57 auxiliary mine sweepers, 2 mine sweep tenders, and 5 landing craft. In the diversionary forces, RCM equipments were installed on 1 destroyer, 2 gun boats, 4 torpedo boats, and 4 sea rescue launches. From this, some idea can be gained of the types of ships selected for RCM protection.

Virtually all of the Naval RCM equipment used in this operation, as was the case in Normandy, was designed by the Radio Research Laboratory. In addition to the equipment carried by the ships themselves, the landings were protected by jamming from RAF aircraft, as well as from a number of Dina-Amplifier combinations operated by a U. S. Signal Corps ground jamming detachment on the island of Corsica. This expedition, known as Beaver II, included two RRL technical ob-

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servers, and a large portion of the jamming equipments used had been crash-produced at the Radio Research Laboratory itself. In addition to jamming during the invasion, listening and intercept work carried out by the Beaver expedition from the Corsica location gave valuable information on the behavior of the German radars as well.

As in the Normandy operation, civilian assistance rendered to the U. S. and British Navies was extremely valuable. Men were loaned from ABL-15 for the occasion. Only eighteen days before the Southern France operation itself, not one installation of RCM equipment had actually been made. Yet by the time of the operation itself, some 95 per cent of the originally planned installations had been completed!

As far as can be determined, countermeasures were as successful during the Southern France operation as in the case of the Normandy invasion. The Germans got very little use out of their equipments. For example, the "Beaver" group in Corsica found that five out of six Coast-Watcher radars left unjammed, went off the air for some reason during the invasion!

II - Pacific Theater

The countermeasures war in the Pacific Theater differed from its counterpart in Europe in several important respects. By comparison, Japanese radars were widely scattered in location and were not encountered in numbers large enough to be of operational significance until late in the war. Moreover, the only Japanese radars of any consequence were relatively low-frequency - in the 70-200 Mc range. They were easier to jam in view of their wider beamwidths and longer pulse lengths.

Radars found on widely separated Japanese islands could be dealt with by means of techniques often simpler than those necessary when large numbers of equipments are concentrated in a small area. For example, in the Southwest Pacific, our Air Forces often successfully put radars out of action by direct attack. However, "radar busting" could not profitably be carried on as we neared the Japanese home islands, where the number of operating radar sets was larger.

In view of the relatively smaller number of Japanese radars, intercept work was operationally more important in the Pacific than in the European areas. Our submarine, surface, and air forces all made effective use of search receivers to warn them of enemy radar; this was done so effectively, that the Japanese, in many instances, restricted the operation of their equipments in order to prevent giving themselves away. Our forces took advantage of Japanese radars almost more often than they jammed them.

The first definite evidence of the existence of Japanese radar came to light during the invasion of Guadalcanal, when U. S. Marines captured a primitive Japanese air-warning set. Two of these same radars were later spotted in photo-reconnaissance pictures of the island of Kiska, and since they would expose any force attacking that island to radar detection, the Army Air Forces lost no time in sending a specially fitted B-24 search plane to the Alaskan theater in the early part of 1943 in order to confirm their suspected nature. The Radio Research Laboratory helped to equip this plane, which was flown to the East Boston Airport for the purpose. Since the SCR587 search receiver could not tune below 100 Mc (the originally suspected frequency of the Japanese radar was 60 Mc) RRL developed a 30-100 Mc (the TN-1) tuning unit especially for this mission in a matter of 19 days! The existence of two Japanese radars was soon verified, and their frequency found to be 98 Mc.

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Figure 63. Aircrew member ejecting Window bundles from B-17

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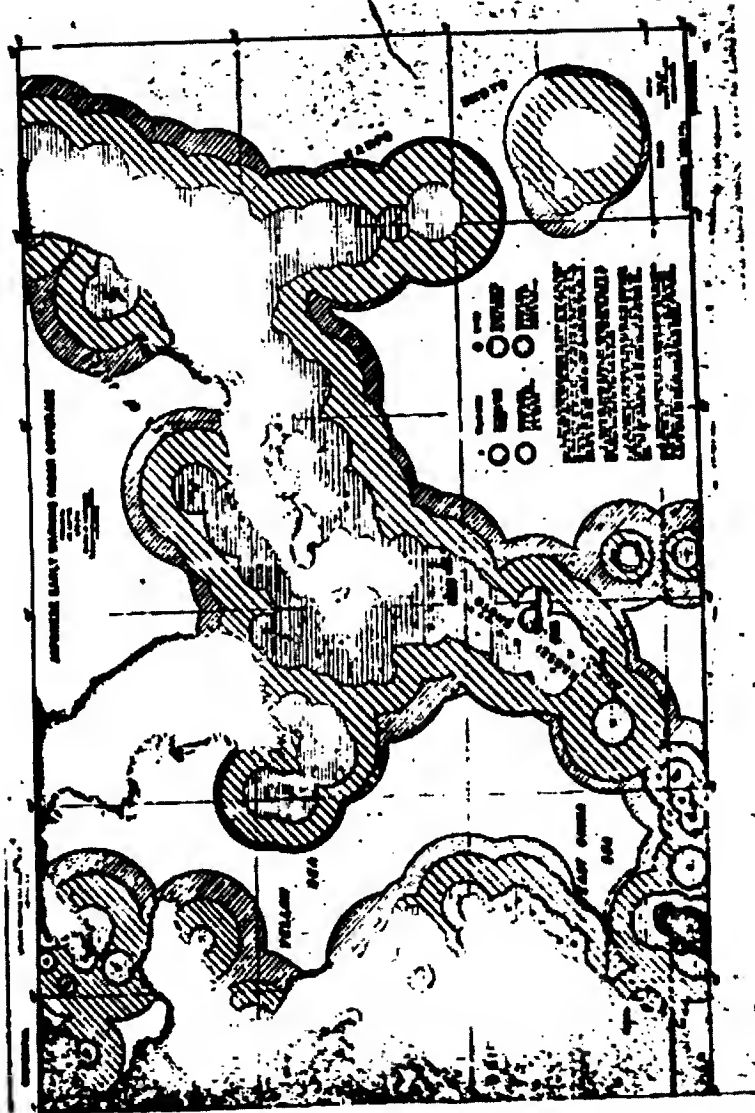


Figure 84. Radar coverage map of Jap Home Islands

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This was the first instance of an enemy radar having been heard on U. S.-built countermeasures equipment carried in a plane.

Steps were taken at home to make sure that these radars would be put out of action on the day of the invasion of Kiska. The island of Amchitka, approximately fifty miles away from Kiska, whose mountainous top was within line-of-sight of that island, was selected as a suitable site for a ground-based jamming installation, known as project "Beaver I." The Signal Corps' First Special Signal Platoon was formed and outfitted with prototype low-frequency jamming transmitters supplied by RRL. An RRL technical observer also accompanied this expedition to Amchitka.

Shortly before the invasion itself, further radar reconnaissance being carried out by Army and Navy patrol planes in the vicinity indicated the possibility of the existence of a third, higher frequency radar on Kiska. This resulted in an urgent request to RRL for a prototype of the newly-developed "Rug" transmitter which would cover the 300 Mc range, and an engineer to accompany this equipment to Alaska on an Air-1 priority.

However, by the time the Beaver Expedition had set up its equipment and placed its receivers in operation, the Japanese had blown up their radars prior to abandoning the island two days in advance of our invasion. As a result, the various jamming equipments were never used; however, the experience gained was very valuable and the Beaver project itself set the pattern of others which were to follow.

In the South Pacific, RCM activities were coordinated by a joint Army-Navy organization known as Section 22 of General Headquarters. In the early days of the war, little more than organized search work, which led to the pinpointing of many Japanese early-warning radars on the islands north of Australia, was needed. The Japanese radars were not plentiful enough, or well organized enough, to constitute any threat to our operations. Some air-warning sets were known to have been turned on only after a bombing attack had begun!

Other activities of Section 22 included training Allied operators in anti-jamming techniques and educating the Forces in that theater to the possibilities of RCM.

Radar search work was carried out by Navy PBY patrol planes - operating at night and known as "Black Cats", by PT boats, and even by submarines. Later on, this work was greatly strengthened by a series of Ferret planes sent over from the States. RRL technical observers accompanied the Ferrets from the very start. Much of the ambiguity of the early radar intercept data received from this theater was resolved after the U. S. Ferrets, with their modern equipment, arrived on the scene. Reports of relatively high frequency radar intercepts, for example, ceased.

When the pace of the Navy's Pacific campaign began to be stepped up, it was soon realized that RCM would have to be handled in a different way in this theater than had been the case in Europe. In the Pacific, the Navy was obliged to deal with not one or two D-days, but instead a whole series. It was not possible to handle RCM by means of teams of experts who were sent to each locality for each particular job. Instead, it was decided that each ship of the Navy should be made self-protecting, and given adequate countermeasures defenses as part of its standard equipment. This decision led to a large-scale shipboard RCM installation program, of a size almost comparable to the installation programs of the Army and Navy Air Forces. (Our Navy included roughly 450 destroyers, 350 destroyer escorts, 250 submarines and 100 cruisers, not all of which, of course, were in the Pacific at any one time.) All ships from destroyer-escort-size on up (including submarines) were given a

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"type allowance" of intercept equipment; all ships from the larger destroyers on up (not including submarines) were given a type allowance of jamming equipment - and a very large percentage of the Pacific Fleet was equipped according to this plan.

Following is a listing of the main types of RCM equipments being installed aboard Naval vessels, as of early in 1945, with comments:

RDO	Search Receiver	40-3400 Mc	Tuning units RRL-developed
SPR-1	Search Receiver	40-3400 Mc	Modification of RRL APR-1 design
SPR-2	Search Receiver	1000-12,000 Mc	Modified RRL Design
RDJ	Pulse Analyzer		
RDP	Panoramic Adapter		
DBM	Direction Finder	90-5500 Mc	RRL Design
TDY	Jammer	60-1200 Mc	Basic Transmitter research done at RRL. TDY antenna system RRL-designed.

All antennas for the above equipments were designed by RRL.

Under the same overall plan, allowances were set up for RCM equipment allocated to carriers (CV's, CVL's), for use in carrier aircraft (TBM, etc.). By the end of the war, these included the following:

APR-1	Search Receivers	40-3400 Mc	RRL-designed
APR-2	Search Receivers	100-1000 Mc	RRL-designed
APR-5	Search Receivers	1000-12000 Mc	RRL-designed
APA-11	Pulse Analyzer		
APA-23	Recorder Attachments		RRL-designed
APA-38	Panoramic adapter		RRL-designed
APT-1	Jammer		RRL-designed
APQ-2	Jammers		RRL-designed
AM-14/APT	Jammer Amplifier		RRL-designed
AM-18/APT	Jammer Amplifier		RRL-designed
APQ-20	Jammer	2000-4000 Mc	RRL-designed

All antennas for these equipments, too, were developed by RRL.

Search receivers were used in surface ships during the original attacks on the Marshall Islands, although Japanese radar was not a factor in those campaigns. Receivers of this type were also used to good advantage, for example, during the shore bombardments of the Kuriles and of Iwo Jima. In the latter instance, our cruisers approached under a condition of radar silence in order to have the advantage of complete surprise.

As the war moved further West, more Japanese radar began to put in its appearance. Fairly effective search light and anti-aircraft fire control radars began to be encountered as our forces approached the Philippine Islands and the Island of Formosa. The Japanese first used Window in October, 1943; by October 1944, our own Naval forces were making good use of this countermeasure.

In addition to its use by the surface forces, RCM was employed to good advantage in the Navy's carrier aircraft. Carrier-based planes making strikes over the Clark Field area in the Philippines, for example, carried Window and Rope to protect them against the Japanese searchlight-controlled radar. Our "night hecklers", teams of fighter and torpedo planes assigned the task of maintaining a continuous

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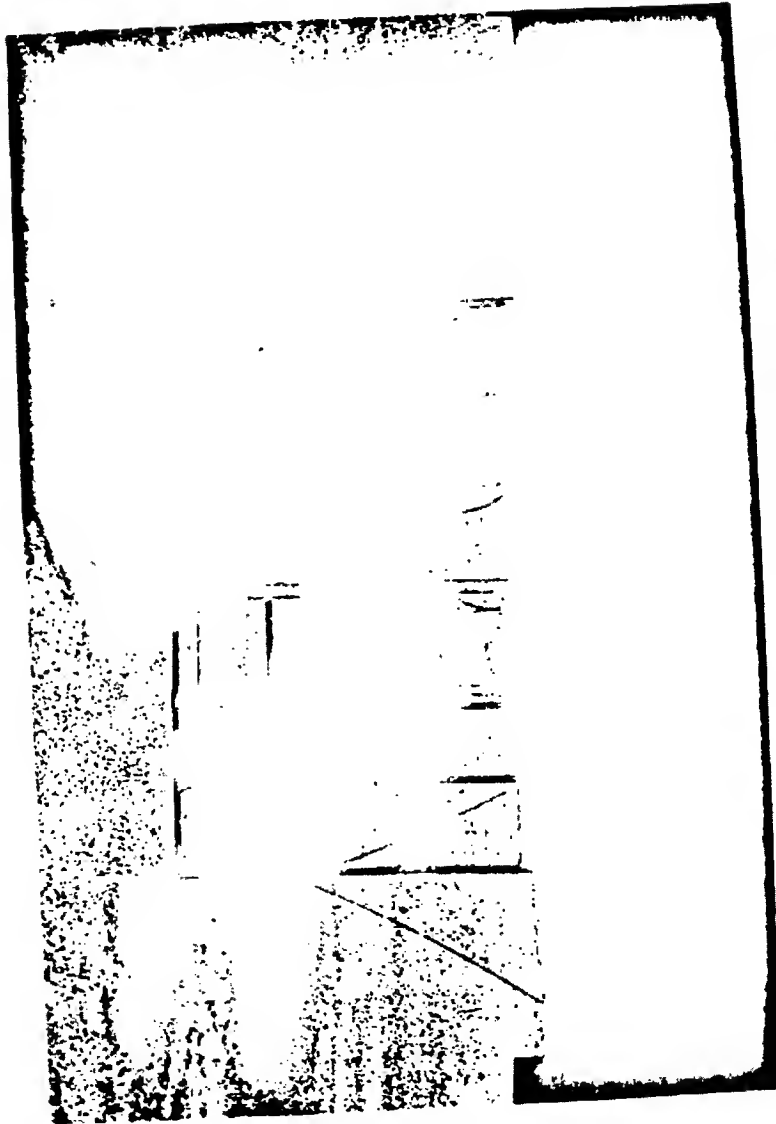


Figure 65. Remains of a Jap radar on the Aleutian Island of Kiska

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Figure 66. Two types of Rope - a countermeasure widely used against the Japs

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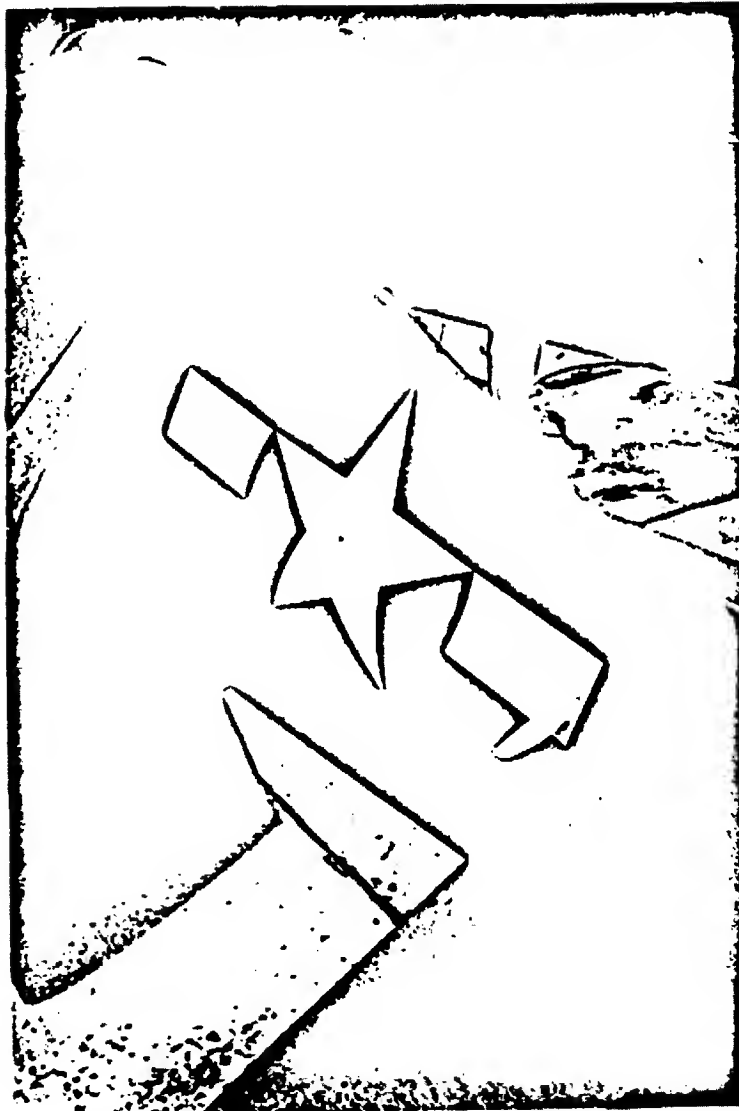


Figure 67. Showing antenna for RCM installation in
Navy carrier-based Fighter plane

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patrol over Japanese airfields when our carriers were in the vicinity, were given the protection of Window and spot jamming RCM installations. These last were operated by the radio operator in the three-man TBM torpedo bombers. Carrier plane RCM was used to good effect; on many occasions, the Japanese radars reacted to our jamming by shutting down or going off the air.

Considerable radar search work was done by the long-range Navy patrol squadrons which paced our land forces during their island-hopping advances. Operated out of advance bases, these planes had the job of searching out Japanese shipping - an excellent opportunity for radar search work as well. Foreseeing this, the Bureau of Aeronautics had set up in 1943 a program for equipping the PB4Y2 "Privateer" search planes with the very latest in radar search and jamming equipment. These planes, of which over 600 were delivered, were introduced on a wide scale at the end of the war. Their allowance of RCM equipment included:

1 AN/APR-1 Search Receiver	RRL-developed
1 AN/APR-2 Recording Search Receiver	RRL-developed
1 AN/APR-5A Microwave Search Receiver	RRL-developed
1 AN/APA-11 Pulse Analyzer	
1 AN/APA-17 Direction Finder (high frequency)	RRL-developed
1 AN/APA-24 Direction Finder (low frequency)	RRL-developed
1 AN/APA-10 Panoramic adapter	
1 AN/APA-23 Recorder Attachment	RRL-developed
1 AN/APT-1 Jamming Transmitter	RRL-developed
1 AN/APQ-2 Jamming Transmitter	RRL-developed
1 AN/APT-5 Jamming Transmitter	RRL-developed

(all antennas for the above were RRL-developed)

Search receivers were widely used aboard U. S. submarines, where their usefulness was immediately recognized. (The first such submarine installation was made as early as August, 1943.) In addition to spotting and locating enemy shore-based radars, our submarines were often enabled by means of their intercept receivers to search out the Japanese shipping which was their primary prey. Later on in the war, both Japanese escort vessels and submarines began to be equipped with radar, most of it a low-frequency portable air-warning set. These radars were not very useful against surface targets, yet could easily be intercepted. During one patrol, the U. S. S. Batfish earned a citation for sinking three enemy subs, all of which were not only detected by means of a search receiver, but also located by the same set, using the directional pattern of the intercept antenna.

U. S. submarines were thus enabled to avoid Japanese air attack by Japanese radar-equipped patrol planes. By listening to the Japanese transmissions, our submarines could tell when they had been detected. If a previously wavering signal should steady down and grow louder, it was time to dive.

The Navy made further use of RCM in the Pacific during invasions such as those at Iwo Jima and Okinawa. According to a carefully worked out plan, landing craft and support vessels were equipped with jammers (most of them AN/ARQ-8, AN/APQ 2, AN/APT-1, etc.) with which to knock out enemy shore-based or airborne radars.

U. S. surface ships, like submarines, were able to avoid Japanese air attack by using search receivers. Japanese-radar-equipped aircraft, which put in their appearance during 1944, became a much more serious threat after the introduction of Kamikaze tactics. Although radar-equipped planes themselves were seldom used

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for suicide attacks, it not infrequently occurred that the radar-equipped planes led others in. Moreover, these "snooper" planes were fond of shadowing our carrier task forces at night - staying as far out of range as possible - yet able to give radio instructions to planes participating in an attack.

By means of their search receivers, our ships could detect the approach of snoopers well before U. S. Fleet radar operators spotted a "bogey" on their screens. As directional antennas became available to the Fleet, it was found possible to determine the direction from which enemy radar signals came, and even to dispatch an intercepting fighter in the proper direction to make an interception before the enemy plane itself had been discovered by radar.

The importance of this application of RCM very greatly increased the Navy's interest in the RRL-developed rotating-reflector direction finder (DBM). Fifty of these in all were crash-produced by the Laboratory for the Bureau of Ships, for installation on such key Fleet units such as Amphibious Command Ships (AGC's).

As might be expected, Japanese radar-equipped planes were not left unmolested when they participated in attacks on our ships. Whenever they approached, they found themselves jammed, either by RRL-developed airborne jammers modified for the purpose, or by the more powerful TDY's. The reaction in these cases was extremely satisfactory; when their radar failed them, the Japanese pilots simply broke off the attack.

Toward the latter part of the war, persistent reports of Japanese S-band surface-search radar came to hand. This was finally verified, in the spring of 1945, by the recovery of one of these radars from a Japanese cruiser sunk late in 1944 during an action in the Philippines. To meet this potential threat (for the Japanese S-band radar was found to be of crude design and low performance) the Navy rushed to completion a modification of the TDY shipboard jammer, making it possible to operate this equipment at 10 Cm. The tubes used in this development were magnetrons, the development of which had been stimulated by RRL's airborne 10 Cm equipment, the AN/APQ-20. The modified TDY's were installed aboard a few battleships and cruisers.

Antennas for these units, as well as all the other antennas of the TDY series, were designed by RRL under an arrangement whereby the leader of the RRL antenna group acted as informal consultant to the Bureau of Ships on antenna problems of every sort.

In addition to carrying out extensive search work, the Army Air Forces in the Pacific theater used offensive countermeasures later on as well; for example, mine-laying flights into Manila Bay were protected by both Window and electronic jamming. The 11th and 13th Air Forces, attacking the relatively heavily defended island of Formosa, were the first to begin systematic jamming of searchlight-control and anti-aircraft fire-control radars around the middle of 1944.

Our very heavy bombers, the B-29's, had been prepared for an RCM war from the very start. When the 73rd Wing was sent out to its bases in India and China in early 1944, the expedition was accompanied by two RRL technical observers who had the job of making sure that the generous supplies of countermeasures equipments supplied with these planes saw the most effective use. In view of the long supply route, the B-29's were given jammers as well as search receivers, in case the former should ever be needed. Flying from bases in India, these planes located a number of enemy equipments in Burma, China, and Japan proper. However, anti-

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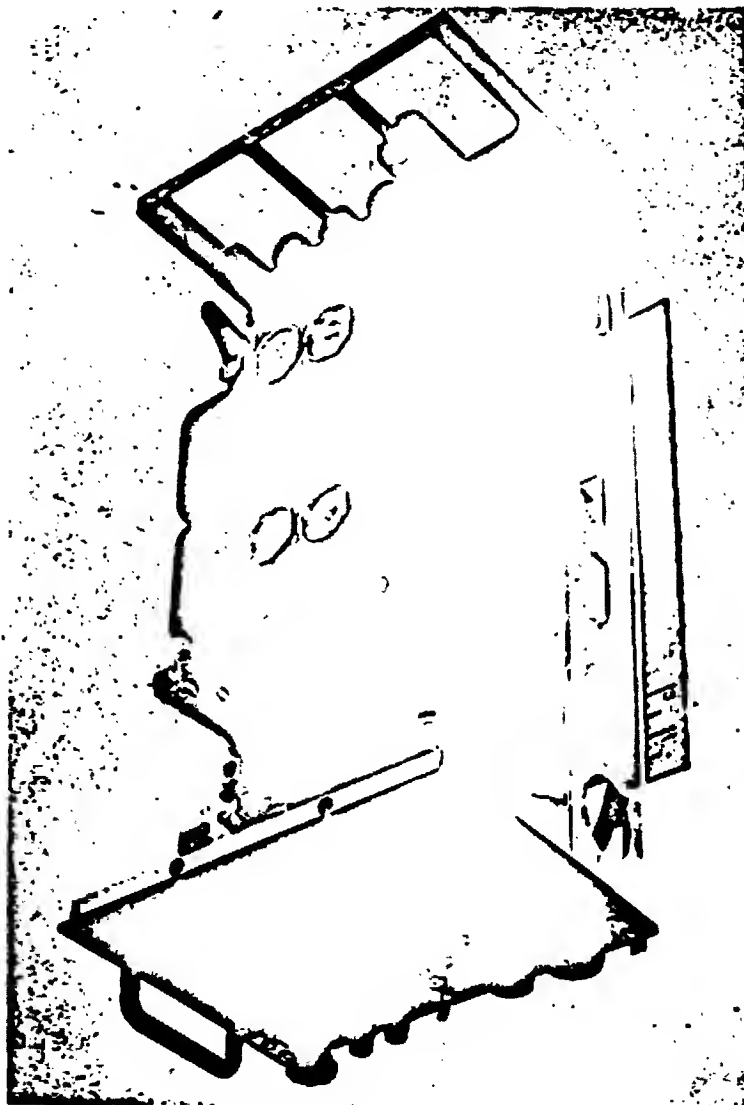


Figure 68. AN/APT-1 200 megacycle jammer - widely used in the Pacific

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411-299

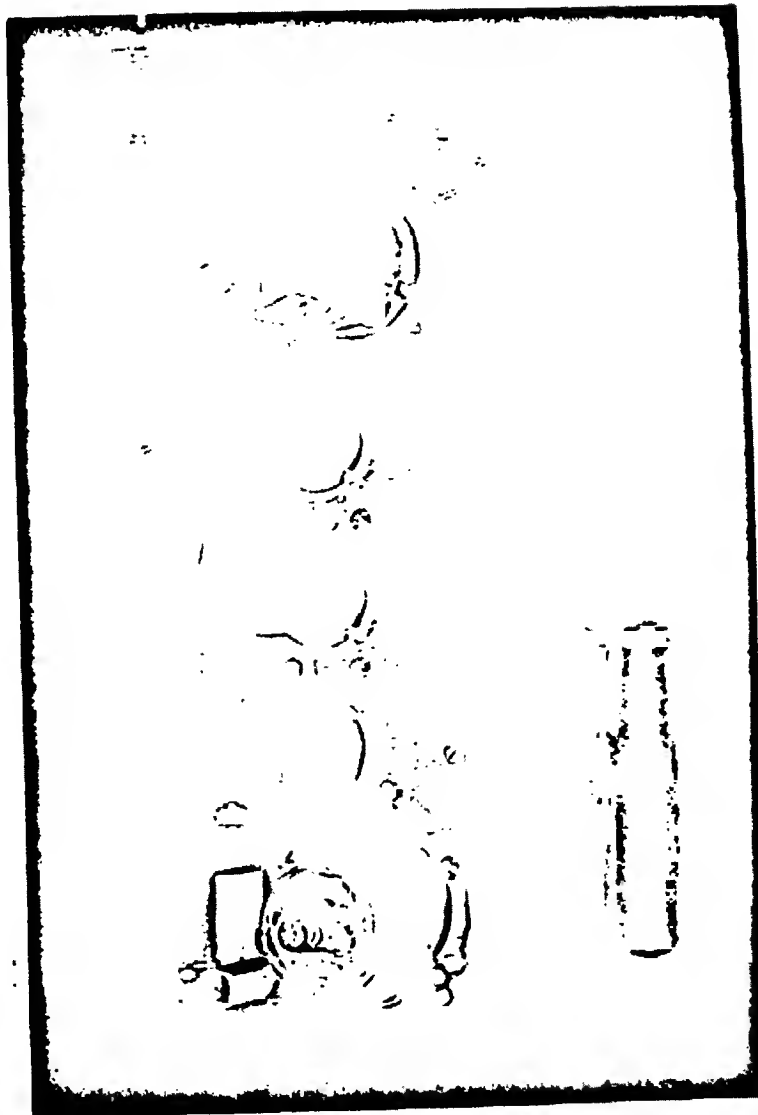


Figure 69. Photomultiplier noise tube and modulator

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411-299

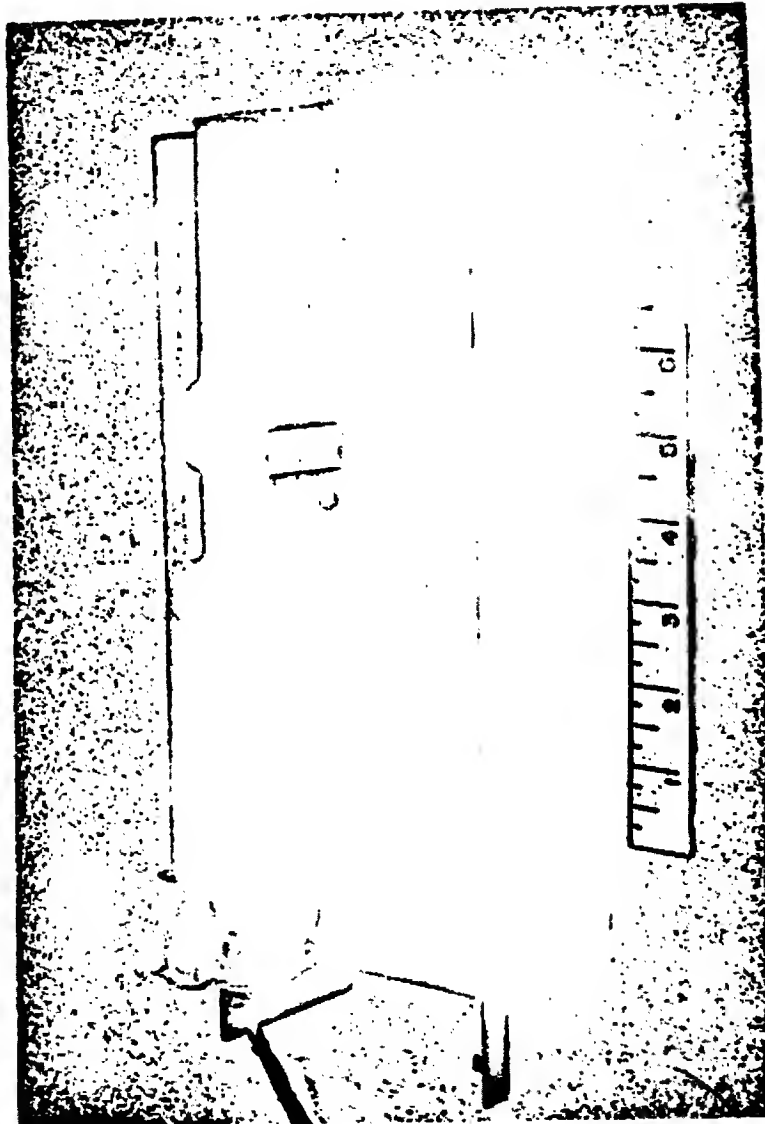


Figure 70. Gas tube noise modulator - more effective and simpler than its predecessor

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411-299

aircraft opposition was then slight, and since it was never possible to demonstrate the connection between enemy radar activity and accurate flak, no jamming was undertaken at the time.

One of the important RCM events in the Pacific war was the first strikes of the 73rd Wing over the Japanese home islands in June, 1944. Intercept data taken during these missions showed that only those Japanese radars already observed in outlying regions, such as the Southwest Pacific Areas, would be encountered over Japan itself. True, there were more radars in Japan, but the fact that no new types were found refuted a frequently-expressed view that the Japanese were "saving up" their best radar for the defense of their homeland. The countermeasures picture was thus greatly clarified.

Active jamming of enemy radars by the B-29's did not begin until the 20th Bomber Command was operating out of its bases in the Mariannas Islands. In late 1944, an all-out jamming program was undertaken by these planes to neutralize the Japanese anti-aircraft fire control radar being encountered in greater numbers over the home islands. Rope was used very extensively as well, and at the end of the war, the operational plan called for the carrying of 720 units (over 600 pounds) of this countermeasure in each aircraft. In general, Window and electronic jamming were employed in the same way as in the European theater.

The B-29's were fortunate, compared to the heavy bombers in Europe, in that each plane left the U. S. equipped with Group A parts for the standard RCM equipments. Inverters, power and antenna cables, and antenna parts were already installed. Thus it was a simple matter to equip each plane for barrage jamming. The daylight squadrons of 11 planes carried one AN/APT-1 or AN/APQ-2 each, with frequencies staggered to cover the 200 Mc band. In addition, two spot jamming operators (each controlling three jammers) were to be carried in each squadron, had the shortage of receivers permitted it. The Japanese 78 Mc gun-laying band was to have been barraged with seven AN/ARQ-8 jammers per squadron of eleven planes; usually, however, no more than one or two of these transmitters was available to each squadron. Some power amplifiers were used with the AN/ARQ-8's, and like the basic equipment itself, many more were on order.

Since the B-29's operated both day and night, it was found that the two methods of operation called for two different RCM procedures. During the daytime, our planes carried out barrage and spot operations whereby each group of planes was made self-protecting. At night, the problem of protecting each individual plane called for a different solution, and at the end of the war, plans were going forward for the construction and operational use of what came to be known as "Porcupine" planes, which were B-29's fitted out with a large number of jamming transmitters and the necessary antennas. It was planned that four of these planes per wing would orbit in the vicinity of the target area, out of range of gunfire, yet within the beamwidth of the wide-beam Japanese radars. The "Porcupines" would then jam any enemy radars which might come on.

Each of the interim "Porcupines" actually used carried six to fourteen transmitters; plans for the final version called for eight 200 Mc barrage jammers, five 78 Mc barrage jammers, and two spot jamming operators for the 200 Mc band. In addition, it seemed likely that amplifiers would have to be carried. About two thousand bundles of rope, weighing one ton, were to be dispensed from the "Porcupines".

B-24 Ferret planes, operating from Guam in support of the Mariannas-based B-29's, had an important assignment at the end of the war. Their task was to map

the radars on the Nanpo Shoto chain of islands which extended from Iwo Jima to Tokyo Bay. For ease in navigation, these islands were followed by the B-29 strikes on their way north, and their early warning radars were earmarked for destruction by bombing and strafing. By the end of the war, the Ferrets had succeeded in radar-mapping this entire chain of islands, and radar-"busting" was to begin as soon as the sites had been photographed by photoreconnaissance planes.

A good idea of the magnitude of the Army Air Forces countermeasures program can be gained from the following tabulation of shipments of RRL-developed equipment to the four theaters which were the largest consumers thereof:

**ARMY AIR FORCES
OVERSEAS SHIPMENTS OF RCM EQUIPMENT TO FEB. 1, 1945
(not including Window)**

Unit	5th and 13th AF SWPA Burma	ETO	MTO	B-29's	TOTAL
AM-14	80	202	310		592
AM-18	80	182	310		572
AM-33		50	250		300
APA-17	3	5	3		11
APA-23					139
APA-24	12	12	8	16	48
APQ-2	2	500	210	171	883
APQ-9	2	over 10,000*	3700		13,702+
APT-1	133	400	310	591	1,434
APT-2	11	3,426	982	569	4,988
APT-3	64	274	46		384
APT-5		329	293	396	1,018
APR-1		15	110		125
APR-2	35	10	8		53
APR-4	36	621*	150	129	936
APR-5A	54	27	25	70	176
APR-7A		20	7	12	39
APQ-8	25	20	5	24	74
TOTAL	537	16,093+	6,727	1,978	25,335+

*Includes February shipments.

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411-299

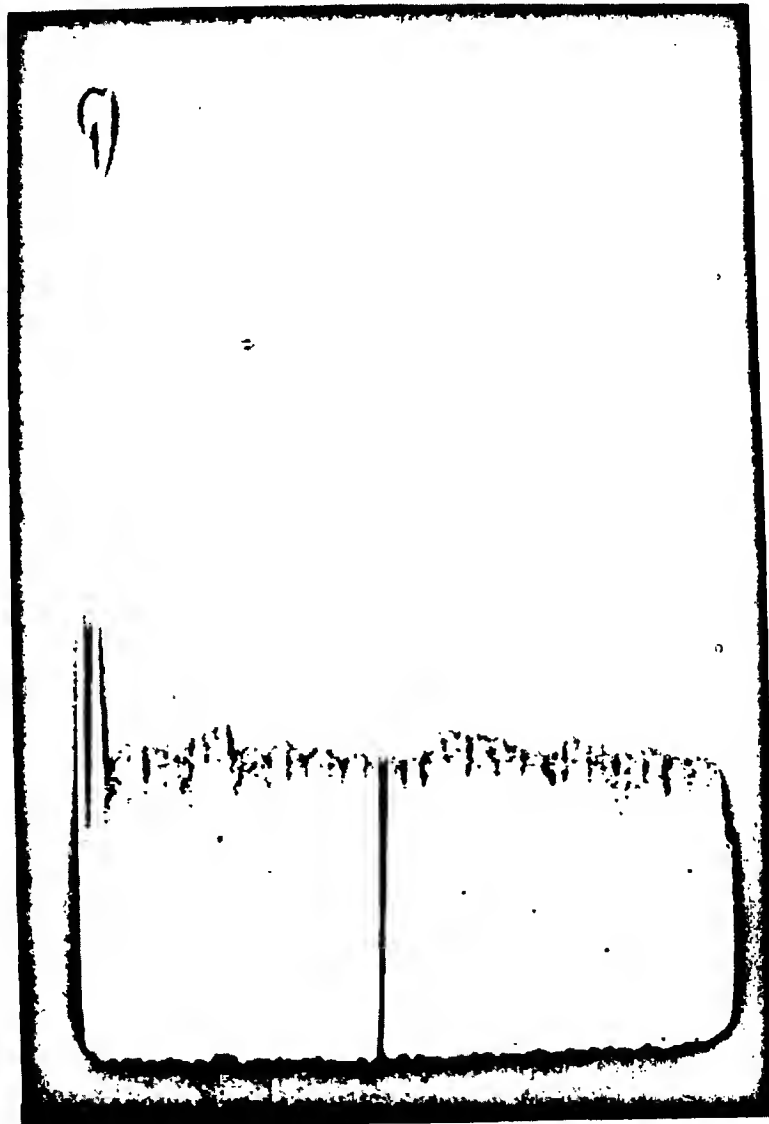


Figure 71. Noise jamming as it appears on a typical radar "A" scope

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411-299

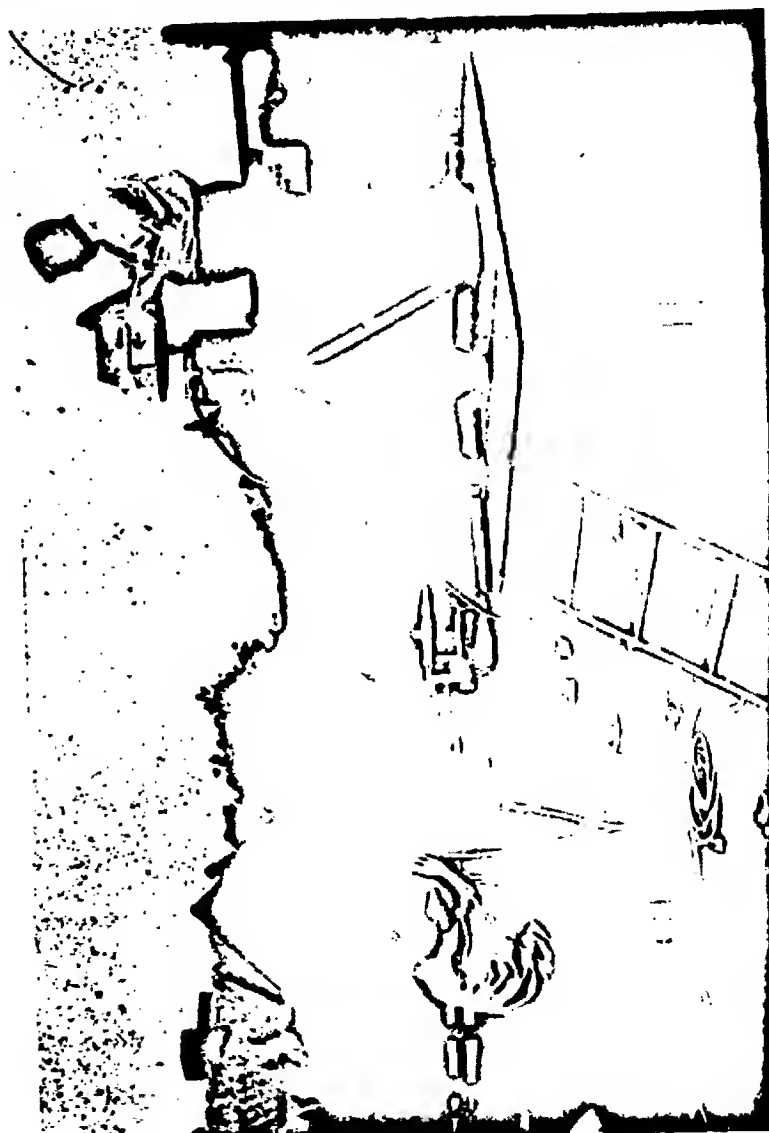


Figure 72. Antenna research in progress on the RRL roof

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VIII. EVALUATION OF RCM

It can be said the Allies' use of radar countermeasures in this war was strikingly successful. For it is certain that our enemies got far less use out of their radars than did the Allies. United States jamming of enemy radar saved thousands of lives, hundreds of planes, and perhaps even ships. By deceiving enemy radars, as was done shortly before and during invasions, U. S. forces not only concealed our intentions but also, in some instances, made enemy radar something which is worse than useless; namely, a source of misleading information. By intercepting enemy radar signals, our forces obtained warning of impending attack, and made German and Japanese radars useful to us rather than to our enemies.

It is plain that due to our countermeasures, the enemy got little out of radar, whereas we got the most out of it. The enemy was, in many instances, afraid to turn on his equipment for fear it would give him away (as was the case with German submarines and Japanese search planes). Yet our radar blind-bombing operation against Germany was virtually unopposed from the countermeasures point of view, although experience at RRL showed that S-band radar can be jammed!

The success of our own use of radar depended, in no small measure, on the enemy's inability to bring countermeasures to bear. For it is surprising that the enemy did not do a better countermeasures job, particularly during those periods when the Allies were the most vulnerable, i.e. - in 1940-1942.

The Germans and Japanese ended the war with very little enthusiasm for radar. It is no wonder that some Germans told our interrogators that "Flak is an outmoded weapon!"

It is remarkable to think that RCM, which was virtually unheard of by the U. S. forces at the time of Pearl Harbor, was practically a household word by the end of the war. Every Naval vessel, from submarines and destroyer escorts on upward, carried its share of countermeasures equipment. Moreover, countermeasures gear was a standard part of the equipment of every bomber, and radar countermeasures was an established activity in the strategic air forces.

It is interesting to examine the reasons why our countermeasures effort was so successful. For it succeeded even though experience showed the impracticability of saving up countermeasures to spring them all at once on the enemy, as was once the plan. In most every case in World War II, countermeasures were used in small quantities against the enemy before any large-scale effort was made. It proved to be necessary, in most instances, to give new developments an operational trial in order to win support for the effort required for their wholesale introduction. Thus it was the successful operational use of 70 Carp jammers in October, 1943, that caused the 8th Air Force to support a program involving the installation of thousands of equipments - each weighing roughly 100 pounds - in operational aircraft.

The gradual introduction of our countermeasures had, in the case of the Germans, a definite value in that it pinned their scientists down to a program of anti-jamming in order to save the enormous Wurzburg radar investment. Had our jamming blitz started out at full speed, the Germans might well have given up any hope of saving this investment and might have bent their efforts in other, more fruitful directions, such as the development of microwave radar.

One of the remarkable circumstances about countermeasures is the fact that they were not very clearly foreseen. Both the Allies and the Germans made the same mistake of having most of their radar concentrated in narrow frequency ranges at the start. Compared to the Germans, however, the Allies were relatively quick and aggressive in making up for this initial oversight. However, as late as 1942, the British estimated that roughly six enemy planes, each carrying a small number of jammers, could have put over 70% of the British radar out of action. To show that we too made the same mistake, the following example is cited. As late as 1943, the radars of the Army's air defense training installations in Florida were all concentrated in such narrow frequency ranges that they were knocked out by only three planes carrying two jammers each during the course of a demonstration! Moreover, even later in the war, U. S. radar magnetron designers had standardized their designs, manufacturing tolerances, etc. to the point where U. S. microwave radars of a given type were, in some instances, all to be found within a frequency band of plus or minus 15 Mc.

At the start of the war, the German Wurzburg radars were all concentrated in a frequency band roughly 10 megacycles wide - a perfect target for countermeasures. Moreover, the German's choice of an operating frequency happened to be a relatively fortunate one from the standpoint of RCM. Although the Germans had pushed their radars up to the highest frequency at which conventional triode tubes and techniques could be made to function successfully, it was possible for the U. S. to start out with Wurzburg jamming transmitters utilizing tubes which were already in production prior to the war. Moreover, this same frequency happened to be one at which Window - or rather Chaff - is very efficient.

However, the biggest reason for the success of United States countermeasures was the aggressiveness with which we applied them. Developments carried out during the war made it possible to increase the power output of jammers for the Wurzburg frequency range from 5 to 150 watts. Moreover, U. S. forces had at their disposal by the end of the war, completed jammer developments which would have given our planes satisfactory jamming coverage up to frequencies approximately five times those actually used by operational German anti-aircraft radars. Had the Germans moved even up into the microwave region, we would have been prepared for them. An important reason for the success of RRL was its good liaison not only with the purchasers of RCM equipment, but also with the ultimate users, in view of the long delay between the development of a device and its introduction in the field on a wide scale. By working informally with all those concerned with the program, RRL found it possible to expedite many mutual agreements and important decisions.

Another large factor in the success of the program was the fact that RRL was willing to make engineering decisions on the basis of what in ordinary practice would be considered insufficient information. The important thing was that decisions were made. Only in this way, could we always keep one step ahead of the enemy. For example, the fishhook antenna was designed and ready before any definite intelligence information existed on the German anti-jamming development based on our use of a vertically-polarized stub.

Moreover, once a decision had been made, the Laboratory stuck to it, and provided the necessary follow-through. Its responsibility for a development did not cease after that development left the Laboratory, but extended all the way through to the analysis and evaluation of its operation in the field.

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411-299

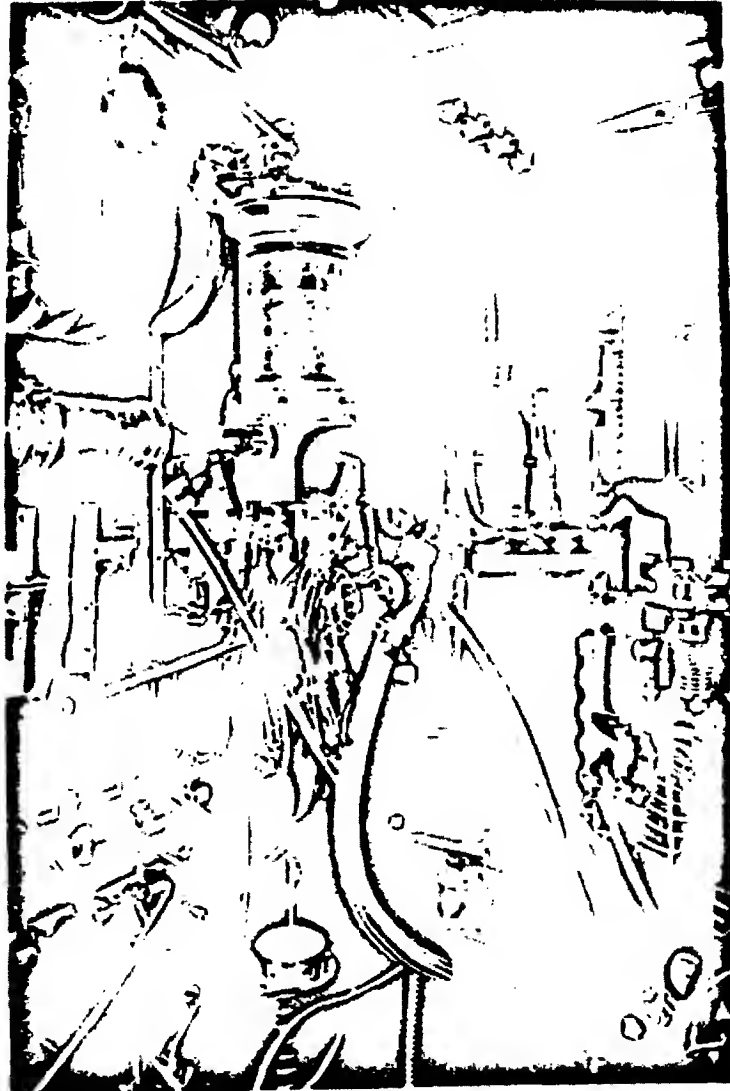


Figure 73. The Resnatron tube should have important post-war applications

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411-299

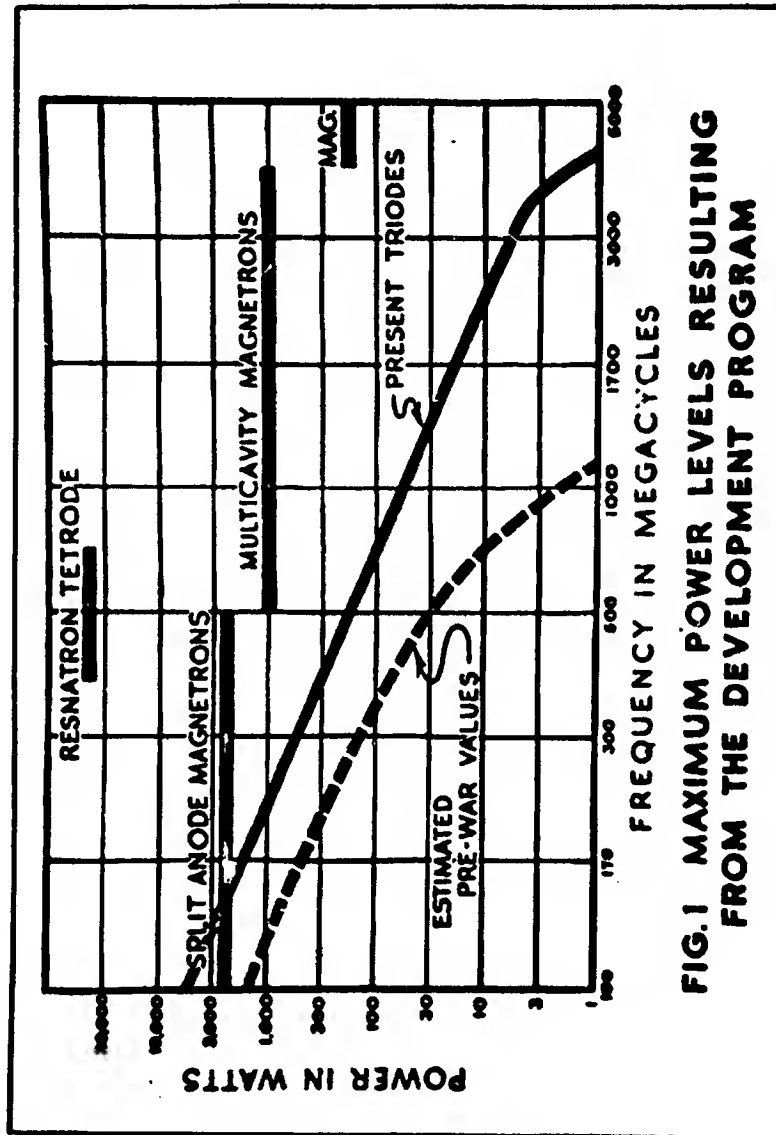


FIG.1 MAXIMUM POWER LEVELS RESULTING FROM THE DEVELOPMENT PROGRAM

Figure 74.

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The fact that RRL was a central activity in its field, made for fast action. The Laboratory was able to serve as a clearing house for information of all kinds, keeping those concerned abreast of developments both technical and tactical in the RCM program. Only nine months after the recruiting of personnel and the ordering of equipment had begun, three important developments were already in the hands of the manufacturer.

The most striking result of the war-time experience with radar countermeasures is the fact that it has obsoleted a whole class of radars. It is certain the reliance will never again be placed on a standardized chain of low-frequency radars which, as the Germans have seen, can be jammed on a systematic basis.

It is likely, therefore, that there will be fewer opportunities for systematic radar jamming in the future. Moreover, the trend in the direction of microwave equipment complicates the radar jamming problem to a considerable extent. Higher beam power, narrower beams, shorter pulse lengths, as well as the greater number of frequency channels in which they may operate, make microwave radars more difficult to jam. In the case of Naval vessels, the present tendency to carry more and more radars will still further complicate the jamming problem. Since some carriers and battleships already have as many as 20 different radar sets aboard, it can be seen that the task of knocking out each one of these radars will be very difficult; it will not be easy even to jam those sets which might be used for main battery fire-control! In the case of aircraft, space and weight limitations have already placed a limit on the number of jammers which can be carried.

Counterbalancing these factors, however, are the following considerations. If the enemy has only a few anti-aircraft radars operating in a given area, it will always be possible for an operator in an airplane to spot jam the radar which happens at the moment to be the most dangerous to him. RCM has therefore complicated the radar problem to the extent that it will be necessary to use more radars - on differing frequencies - for each tactical application. While it may be said that this war has ended the honeymoon of radar countermeasures, it is also true that RCM has made radar a more expensive proposition.

One phase of radar countermeasures will always be important - and that is radar investigation or reconnaissance work. It will always be desirable to find out how much radar the enemy has, where he has deployed it, and how he is using it. Knowing the location of a radar, is often very nearly as valuable as being able to jam it. The search phase of countermeasures will always have importance even in cases where the jamming phase does not.

It is important to realize, from the standpoint of future radar planning, that it is imperative for us to spread our radar frequencies, if there is to be any security against countermeasures. The experience of this war has shown that it is perfectly possible to jam microwave radars efficiently, provided these are operating within a relatively narrow frequency range. We cannot afford to be complacent about our radar defenses, unless their operating frequencies are widely spread and are not standardized in particular bands as has been done in the past. The success of our radar-aided blind-bombing campaign, for example, was dependent on the fact that it was essentially unopposed - from the countermeasures point of view - a circumstance which cannot be relied upon to recur!

CONFIDENTIAL

CONFIDENTIAL

APPENDIX A

SUMMARY OF PRODUCTION
OF RRL-DEVELOPED EQUIPMENTS*

TRANSMITTERS

RRL Project No.	Service Nomenclature	Brief Descriptive Title	NRC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost	Total Orders	Value
A-500	AN/MPQ-1	High Power Mobile Jamming Transmitter. 480 - 500 Mc	3	\$ 1,910,000		\$		\$
B-2000	AN/APT-3	Airborne Transmitter 85-135 Mc			1,105	2,521,000		
B-2000	AN/SPT-3	Shipborne Transmitter 85-135 Mc			60	125,500		
B-2200	AN/SPT-1	Shipborne Transmitter 90-220 Mc			50	110,400		
B-2200	AN/APT-1	Airborne Transmitter 90-220 Mc	7	11,200	6,195	8,860,300		
B-2800	AN-14/APT	Power Amplifier 85-150 Mc	10	20,618	2,672	2,247,000	2,775	3,198,300
B-2900/ 3200	AN/ARQ-8	Low Frequency Transmitter and Receiver. 25-104 Mc	50	127,190	1,210	2,048,500	2,656	3,274,600
B-3400	AN-18/APT	High Power RF Amplifier 140-210 Mc			1,827	1,716,900	2,600	2,202,000
B-4100	AN-33/ART	Airborne Power Amplifier 20-100 Mc			1,735	1,638,900		
F-902	AN/SPT-2	Shipborne Transmitter 450-720 Mc			400	100,400		
F-1500	AN/APQ-2	Airborne Transmitter 200-550 Mc			8,265	4,014,500	8,615	4,184,800
F-1500	AN/SPT-4	Shipborne Transmitter 220-550 Mc			719	311,100		
F-2500	AN/APQ-9	Airborne Transmitter 475-585 Mc			14,453	7,974,000	16,393	8,776,800
F-2500	AN/SPT-5	Shipborne Transmitter 475-585 Mc			240	85,650		
F-2800	AN/UPT-T1	Practice Jamming Transmitter	2	4,000	105	238,700		
F-3300	TDY	Shipborne Magnetron Transmitter 350-800 Mc			1,538	7,847,000		
F-3400	AN/APT-4	Airborne Magnetron Transmitter 150-780 Mc			2,192	6,576,000	2,387	11,935,000

*Based on Transition Department Final Report - 12-1-45

(1) This column indicates the number of units provided for the Services with transfer of funds from Services to NRC.

CONFIDENTIAL

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APPENDIX A

411-299

SUMMARY OF PRODUCTION
OF NRL-DEVELOPED EQUIPMENTS*

TRANSMITTERS

NRL Project No.	Service Nomenclature	Brief Descriptive Title	NRL CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost	Total Orders	Value
F-3500	AN/APT-5	Airborne Transmitter 350-1200 Mc		\$	6,763	\$ 6,525,000	11,830	\$ 10,726,000
F-3500A	AN/SPT-6 AN/SPT-6A	Shipborne Transmitter 350-1200 Mc	6	26,395	75	266,600	110	431,800
F-4800	AN/APT-9	Airborne Transmitter 300-2500 Mc				22,910		
F-902	AN/APT-2	Airborne Transmitter 450-720 Mc			7,270	2,916,500	8,912	3,250,000
		Totals	78	2,099,403	56,874	56,146,860	56,272	47,979,300

APPENDIX A

SUMMARY OF PRODUCTION
OF NRL-DEVELOPED EQUIPMENTS*

JAMMING SYSTEMS

NRL Project No.	Service Nomenclature	Brief Descriptive Title	NRL CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	(1) Del- iver- ies	Cost	Total Orders	Value
F-5100	AN/APQ-20	Jamming System (Crash Model)		\$	56	\$ 746,500	150	\$ 2,230,000
D-2200								
M-4902								
Q-1911								
Q-1912								
A-2608								
M-2415								
A-2600/ 2700	APR-5A							
F-5150	AN/APQ-27	Jamming System (Production Model) Remote Transmitter Tuning					1,182	20,000,000*
D-2200								
M-4902								
Q-1911								

*Based on Transition Department Final Report - 12-1-45

*Cancelled

(1) This column indicates the number of units provided for the Services with transfer of funds from Services to NRC.

CONFIDENTIAL

CONFIDENTIAL

411-299

APPENDIX A

3

SUMMARY OF PRODUCTION OF RRL-DEVELOPED EQUIPMENTS*

JAMMING SYSTEMS

RRL Project No.	Service Nomenclature	Brief Descriptive Title	NRLC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost	Total Orders	Value
Q-1913B	AN/APQ-27	Jamming System (Production Model) Remote Transmitter Tuning		\$		\$	1,182	\$ 20,000,000*
M-6807								
M-2415								
A-2600/ 2700	APR-5A							
S-9000	DOGT	S-Band Shipborne Jamming System					7	296,242
		Totals			56	746,500	2,521	22,526,242

APPENDIX A

SUMMARY OF PRODUCTION OF RRL-DEVELOPED EQUIPMENTS*

RECEIVERS

RRL Project No.	Service Nomenclature	Brief Descriptive Title	NRLC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	(1) Del- iver- ies	Cost	Total Orders	Value
A-2600 A-2700	AN/APR-5A (AN/SFR-2)	Microvave Search Receiver 1000-6000 Mc		\$	3,432	\$ 4,950,600	5,500	7,931,000
C-1100	AN/APR-2	Panoramic Search Receiver 90-1000 Mc			225	534,000		
C-1600	AN/APQ-14	"Moth" Receiver 90-250 Mc			5	29,000	25	15,000
C-1900	AN/APA-4B	Airborne Homing System 90-300 Mc	25	100,000			125	200,000
D-101	TU-17	Tuning Unit 75-300 Mc			8,760	\$ 8,371,650	14,928	14,842,050
	TU-2 TU-50B							
D-102	TU-3	Tuning Unit 300-1000 Mc			8,730	\$ 9,059,050	14,928	16,092,050
	TU-1B TU-57B							
D-103A	TU-59B or TU-4A	Tuning Unit 1000-3300 Mc			263	92,050		

*Based on Transition Department Final Report - 12-1-45

*Cancelled

(1) This column indicates the number of units provided for the Services with transfer of funds from Services to NRLC.

CONFIDENTIAL

CONFIDENTIAL

APPENDIX A

411-299

SUMMARY OF PRODUCTION OF RRL-DEVELOPED EQUIPMENTS*

RECEIVERS

RRL Project No.	Service Nomenclature	Brief Descriptive Title	NRC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost	Total Orders	Value
D-104	TH-1	Tuning Unit 40-105 Mc		\$	8,376	\$ 3,948,550	14,928	\$ 7,442,050
	TH-16 TU-56A							
D-1003	AN/APR-1	Radar Search Receiver 40-3300 Mc			2,571	1,796,400	3,744	2,600,000
D-1005	AN/APR-4	Radar Search Receiver 40-3300 Mc			4,356	8,580,000	7,807	15,500,000
D-1500	TH-4	Tuning Unit 1000-3300 Mc			1	586	6,858	4,000,000
D-1800	AN/APA-23	Tape Recorder for Search Receivers			1,496	1,637,000	2,283	2,511,300
D-2100	AN/APR-7	Search Receiver 1000- 3500 Mc	25	14,650	100	75,000		
		Totals	50	114,650	38,415	39,073,886	71,126	71,133,450

APPENDIX A

SUMMARY OF PRODUCTION OF RRL-DEVELOPED EQUIPMENTS*

ANTENNAS

RRL Project No.	Service Nomenclature	Brief Descriptive Title	NRC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	(1) Del- iver- ies	Cost	Total Orders	Value
A-2608	AS-125/APR	Tilted Cone and High-Pass Filter 1000-3500 Mc		\$	7,831	121,364	9,920	143,006
A-2612	AS-44/APR-5	Cone and High-Pass Filter 1000-3500 Mc			2,088	64,696	3,280	101,680
A-2608	CV-92	Blister for A-2608			1,010	5,283	2,210	10,792
P-2307	C-157/AP	Meter Control Box for AS-168/AP Pick-up Antenna			1,500	17,175		
P-2308	AS-168/AP	Pick-up Antenna			5,000	49,000		
P-3701	AS-71/SPT-2	Dipoles and Corner Reflector 450-720 Mc			1,975	151,080		
P-3702	AS-145/SPT-6	Dipoles and Corner Reflector 625-1250 Mc			160	13,600		

*Based on Transition Department Final Report - 12-1-45

(1) This column indicates the number of units provided for the Services with transfer of funds from Services to NRC.

CONFIDENTIAL

CONFIDENTIAL

411-299

APPENDIX A

5

**SUMMARY OF PRODUCTION
OF RRL-DEVELOPED EQUIPMENTS**

ANTENNAS

RRL Project No.	Service Nomenclature	Brief Descriptive Title	NDRG CRASH		SERVICE PROCUREMENT		Total Orders	Value
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost		
P-3903	AS-263/UPT	Dipoles and Corner Reflector 175-550 Mc	20	12,500	70	32,000		\$
P-4701	AS-236/SPT	Dipoles and Corner Reflector 750-1700 Mc			105	28,400	120	48,609
J-303	AS-33	Thick Stub 460-775 Mc			32,987	583,097	39,715	715,976
J303	AS-132	Thick Stub 460-775 Mc			8,928	201,071	11,452	256,964
M-313	AT-36/APT	16 1/2" Thick Stub with Mount- ing Plate 150-220 Mc			13,099	254,196	19,787	405,196
M-313	AT-37/APT	22 1/2" Thick Stub with Mount- ing Plate 113-150 Mc			12,481	288,278	20,971	484,000
M-313	AT-38/APT	29" Thick Stub with Mount- ing Plate 93-113 Mc			27,344	608,872	46,908	1,060,000
M-313	AT-41/APT	16 1/2" Thick Stub Mounted at 45 Degrees with Mount 150- 220 Mc			10,612	301,106		
M-313	AT-42/APT	22 1/2" Thick Stub Mounted at 45 Degrees with Mount 113- 150 Mc			11,798	341,066		
M-313	AT-43/APT	29" Thick Stub Mounted at 45 Degrees with Mount 93- 113 Mc			11,798	363,679		
M-313	AT-52/APT	16 1/2" Thick Stub 150-220 Mc			2,450	9,140	4,292	67,178
M-313	AT-53/APT	22 1/2" Thick Stub 113-150 Mc			2,170	38,364	4,292	73,124
M-313	AT-54/APT	29" Thick Stub 93-113 Mc			2,750	47,122	4,292	74,032
M-318	AT-114/APT	Thick Stub with Connector for RG-14/U 150-220 Mc			1,628	31,921		
M-801	AS-25/APR	30" Antenna 90-420 Mc			25	625		
M-801	AS-26/APR	Cone 420-1000 Mc			1,643	74,904	2,114	80,704
M-801	AS-124/APR	Cone Mounted at 45 Degrees 215-3000 Mc			2,385	87,827	3,877	128,857
M-801	CAOW-66131	Cone with Half Ground Plane 215-3000 Mc			3,544	492,734	4,624	644,000
M-801	CAOW-66132	Stub with Half Ground Plane 90-300 Mc			2,064	135,700	4,020	264,000
M-801	AN-149	Stub 90-420 Mc			330	8,580		
M-801	AN-150	Cone 420-1000 Mc			330	31,340		

*Based On Transition Department Final Report - 12-1-45

(1) This column indicates the number of units provided for the Services with transfer of funds from Services to NDRG.

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6

APPENDIX A

411-299

SUMMARY OF PRODUCTION
OF RRL-DEVELOPED EQUIPMENTS*

ANTENNAS

RRL Project No.	Service Nomenclature	Brief Descriptive Title	NDRG CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost	Total Orders	Value
M-907	AS-65/APQ2	Stub Antenna Kit with Base 200-700 Mc		\$	9,728	258,334	11,689	\$ 310,000
M-1201	AS-37/SPT-4	Shipborne Dipole and Re- flector 340-400 Mc			1,347	94,376		
M-1203	AS-67/APQ2B	Thick Stub 195-575 Mc			2,189	112,392	2,515	129,000
M2101	AT-49/APR AT-49A/APR	Cone Antenna 275-3000 Mc			19,100	285,414	23,134	413,800
M-2102	AS-115/APT	Cone Antenna 275-3000 Mc			1,628	40,829		
M-2202	AS-69/APT	Crossed Bent Dipole 535- 700 Mc			48,636	1,988,197	53,374	2,043,814
M-2202	CU-42/APT	Conversion Unit for M-2202			300	3,270		
M-2202	CW-129	Blister for M-2202			500	3,475	1,000	6,950
M-2204	CW-130	Blister for M-2204			7,802	271,524	13,683	475,000
M-2204	AS-251/AP	Crossed Sleeve Dipole 440-660 Mc			5,673	165,550	9,401	259,695
M-2102	CW-33	Blisters for M-2102			125	3,368		
M-2102	CW-33/APR4	Blisters for M-2102			11,951	363,112		
M-2404	SA-14/APR-1	RF Switch			1,706	173,142	1,726	175,000
M-2404	SA-67/SFR-1	RF Switch			535	27,961		
M-2408	AS-56/SFR-1	Thick Dipole 75-300 Mc			933	59,450	951	60,000
M-2409	AS-57/SFR-1	Double Cone 300-1000 Mc			931	72,625	951	74,000
M-2413	SA-44/SFR-1	Six Position RF Switch			2,681	172,252		
M-2415	SA-44A/SFR-1	RF Switch			1,371	89,115	1,476	100,815
M-2406	CU-19/SFR-1	Conversion Unit for M-2408			906	157,301		
M-2409	CU-27/SFR-1	Conversion Unit for M-2410			906	153,048		
M-2508	AS-49/TPT-1	Dual Dipole end Reflector 90-150 Mc			60	32,050		
M-2508/ 11	AS-49/TPT-1 AS-50/TPT-1	Dual Dipole and Reflector 90-210 Mc	14	4,900				
M-2511	AS-50/TPT-1	Dual Dipole and Reflector 150-210 Mc			60	31,150		
M-2801	CU-44/APT	Conversion Unit for M-2803			1,120	50,580		

*Based on Transition Department Final Report - 12-1-45

(1) This column indicates the number of units provided for the Services with transfer of funds from Services to NDRG.

UNCLASSIFIED

UNCLASSIFIED

411-299

APPENDIX A

7

SUMMARY OF PRODUCTION
OF RRL-DEVELOPED EQUIPMENTS*

ANTENNAS

RRL Project No.	Service Nomenclature	Brief Descriptive Title	NERC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost	Total Orders	Value
M-2802	CU-43/APT	Conversion Unit for M-2804		\$	600	\$ 27,835		\$
M-2901	CAKZ-66/AHN CAKZ-66/AJA	Shipborne Dipole 345-600 Mc			125	23,800	440	83,500
M-2902	CAKZ-66/AHN CAKZ-66/AJB	Shipborne Dipoles 645-800 Mc			125	22,250	440	78,200
M-2903	CAKZ-66/AJN	Shipborne Dipole 175-350 Mc			6	1,800	328	106,800
M-2904	CAKZ-66/AEJ	Shipborne Dipole 85-175 Mc			470	222,500	770	312,500
M-2906	CAKZ-66/AXL CAKZ-66/AJT	Shipborne Dipole 145-275 Mc			361	196,180		
M-2907	CAKZ-66/AKN CAPR-66/AJX	Shipborne Dipole 265-530 Mc			421	173,050	1,421	573,050
M-2908	CAKZ-66/AJY CAPR-66/ALT	Shipborne Dipole 435-820 Mc			400	186,500	1,400	651,500
M-2910	CAKZ-66/AJR CAPR-66/ALU	Shipborne Dipole 790-1410 Mc			285	102,500	1,360	490,000
M-2924	CAPR-66/ALQ	Shipborne Dipole 88-174 Mc					1,000	400,000
M-2926	CAPR-66/ALR	Shipborne Dipole 145-310 Mc					1,000	400,000
M-3010	TS-189/U	Test Oscillator for M-3000			464	75,413	486	79,000
M-3203	AS-181/APT AB-87	Antenna Kit and Mount 195-675 Mc					1,139	274,318
M-4131	OCY	Test Unit for IBM			15	56,850		
M-4703		Circularly Polarized Horn and Reflector 2500-3750 Mc			111	222,000	285	570,000
M-6001	AS-246/AP	Broadbanding Transmitting S-Band Cone Antenna			25	1,000		
Z-2902		Filter for CAOW			1,990	34,851	2,548	45,000
		Totals	34	17,400	293,701	10,337,210	314,491	12,674,060

*Based on Transition Department Final Report - 12-1-45

(1) This column indicates the number of units provided for the Services with transfer of funds from Services to NERC.

UNCLASSIFIED

UNCLASSIFIED

8

APPENDIX A

411-299

SUMMARY OF PRODUCTION
OF RRL-DEVELOPED EQUIPMENTS*

DIRECTION FINDING EQUIPMENT

RRL Project No.	Service Designation	Brief Descriptive Title	NRC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost	Total Orders	Value
C-2100B	AN/ARD-3	Direction Finder 350-400 Mc		\$	200	\$ 229,050		\$
C-2100B	AN/APA-24	Direction Finder 100-750 Mc			310	358,000	494	550,678
C-2100G	AN/APA-42	Direction Finder 60-750 Mc			40	52,000	375	395,000
C-2110	AS-242	Head for AN/APA-24 100-165 Mc	3	675	300	32,213	1,300	118,563
C-2116		Head for AN/APA-24 165-275 Mc	3	800				
M-2300		Direction Finder 300-1000 Mc	15	53,464				
M-2600	CKQA	Shipborne Direction Finding System 300-1000 Mc	25	154,157	5	21,000		
M-3000	AN/APA-17	Airborne Broadband Direction Finding System 250-1000 Mc			1,470	3,503,575	2,315	5,731,800
M-4100	DBM	Broadband Direction Finding System 250-1000 Mc	25	212,500	300	3,477,800	500	5,699,800
M-4502		Microwave Direction Finding Antenna Head for M-2300 1000-5000 Mc	4	5,000				
M-6200	AS-222/APA- 17	Low Frequency Bi-Directional Direction Finding Antenna Assembly for AN/APA-17, 70-200 Mc	25	25,000			525	450,000
M-4504	AS-186/APA- 17	Microwave Direction Finding Antenna Head for AN/APA-17 1000-5000 Mc	11	15,950	1,014	362,816	1,195	428,000
M-6400	AS-108B/ APA-17	Airborne Direction Finding Head 135-2100 Mc			241	59,819	1,098	272,000
		Totals	111	467,546	3,880	8,096,273	7,802	13,645,841

*Based on Transition Department Final Report - 12-1-45

(1) This column indicates the number of units provided for the Services with transfer of funds
from Services to NRC.

UNCLASSIFIED

UNCLASSIFIED

411-299

APPENDIX A

9

SUMMARY OF PRODUCTION
OF NRL-DEVELOPED EQUIPMENTS
TEST AND TRAINING EQUIPMENT

NRL Project No.	Service Nomenclature	Brief Descriptive Title	MERC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost	Total Orders	Value
B-2700	EC-1255A	High Frequency Wavemeter 70-145 Mc		\$	800	240,000		\$
B-3100	TS-92/AP	Alignment Indicator for Double-Peaked Amplifier 20-250 Mc			1,600	811,200	2,377	1,123,800
D-1203	TS-54/AP	Panoramic Spectrum Analyzer 80-1010 Mc					10	10,000
P-2200	TS-52/APQ1	Pulsed RF Signal Generator 460-600 Mc					10	7,500
P-2305	TS-131/APT	Transmitter Output Indicator			4,250	425,000	8,576	857,600
P-3600	TS-53/AP	Carpet Checker 11 200-700 Mc			35	35,000	420	420,000
P-4100	RF-9/UPT	Practice Oscillator	20	1,720	575	86,250		
P-523A	TS-47/APR TS-109/SPT	Test Oscillator 40-500 Mc			2,652	1,415,200	3,702	1,976,000
P-525A	AN/TPC-T2	Training Signal Generator 90-270 Mc			70	57,000	200	168,300
P-4805		Test Cavity for 2C3C Vacuum Tubes	7	8,400				
U-700	RAT-NAME VI	Training Signal Generator 500-1000 Mc			131	209,400	800	1,279,000
U-1100	TS-406/UP	Spark Excited Signal Generator 1000-3500 Mc			300	78,000	540	140,400
Z-1600	TS-118/AP	RF Power Indicator			1,065	319,500		
		Totals	27	10,120	11,478	3,676,550	16,635	5,978,600

*Based on Transition Department Final Report - 12-1-45

(1) This column indicates the number of units provided for the Services with transfer of funds from Services to MERC.

UNCLASSIFIED

UNCLASSIFIED

10

APPENDIX A

411-299

SUMMARY OF PRODUCTION
OF RRL-DEVELOPED EQUIPMENTS*

ANTI-JAMMING DEVICES

RRL Project No.	Service Nomenclature	Brief Descriptive Title	MIRC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	(1) Del- iver- ies	Cost	Total Orders	Value
E-510	Mod. 1.42 for CW-55 JAB	Plug-in High-Pass Video Filter for Mark III and IV Radar		\$	1,500	\$ 15,000		\$
E-515	CAOS-50/AEY	Very High-Pass Amplified Video Filter for Mark III and IV and SCR-296A			700	35,000		
E-1300	TS-109/SPA	Interference Generator (AJ Trainer)			40	40,000		
		Total			2,240	90,000		

APPENDIX A

SUMMARY OF PRODUCTION
OF RRL-DEVELOPED EQUIPMENTS*

WINDOW

RRL Project No.	Service Nomenclature	Brief Descriptive Title	MIRC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	(1) Del- iver- ies	Cost	Total Orders	Value
G-1107	A-1	Double Tape Stripper		\$	18,205	\$ 2,272,500		\$
G-1107	A-1	Fighter Dispenser			1,620	1,200,000		
G-502	OCA-3	12" Chaff Cutter	62	26,000	25	11,000		
G-503	OCA-2	18" Chaff Cutter	99	70,000	345	220,000		
G-500	CHA-2	Paper Backed Bent Chaff 347-404 Mc			1,148,000 lbs	1,630,000		
G-500	CHA-3	Paper Backed Bent Chaff 510-595 Mc			2,160,000 lbs	3,124,000		
G-500	CHA-3 RR-5/U	Embossed Bent Chaff 520-600 Mc			284,000	394,000		
G-500	CHA-4	Paper Backed Bent Chaff 660-770 Mc			16,150	23,000		
G-500	CHA-5	Paper Backed Bent Chaff 2700-3400 Mc			28,000	38,500		
G-500	CHA-5	Paper Backed Bent Chaff Taped 2700-3400 Mc			806,000	192,000		
G-500	CHA-5 T	Paper Backed Bent Chaff- Taped 2700-3400 Mc			66,000	106,000		

*Based on Transition Department Final Report - 12-1-45

(1) This column indicates the number of units provided for the Services with transfer of funds
from Services to MIRC.

UNCLASSIFIED

UNCLASSIFIED

411-299

APPENDIX A

11

SUMMARY OF PRODUCTION
OF RRL-DEVELOPED EQUIPMENTS*

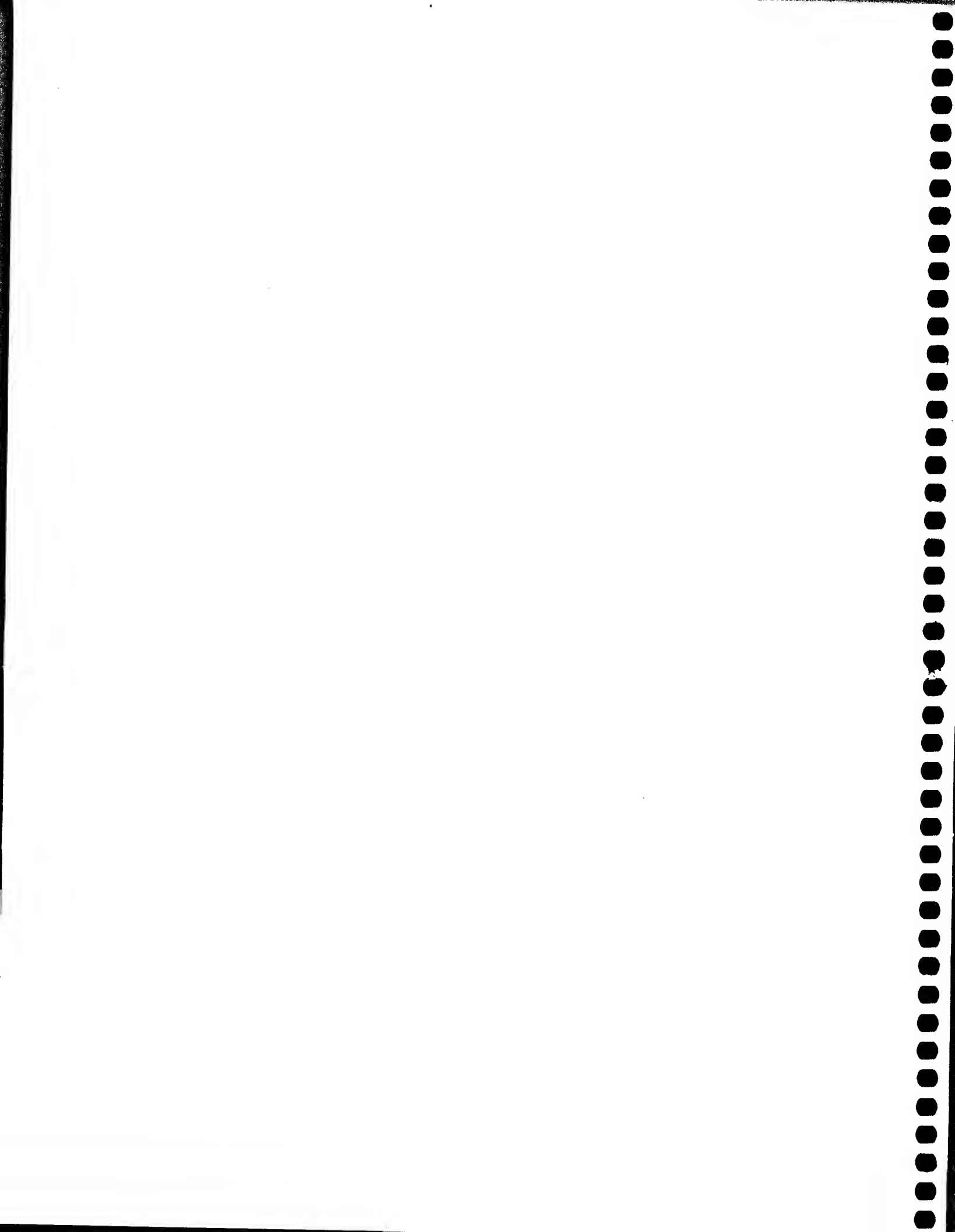
WINDOW

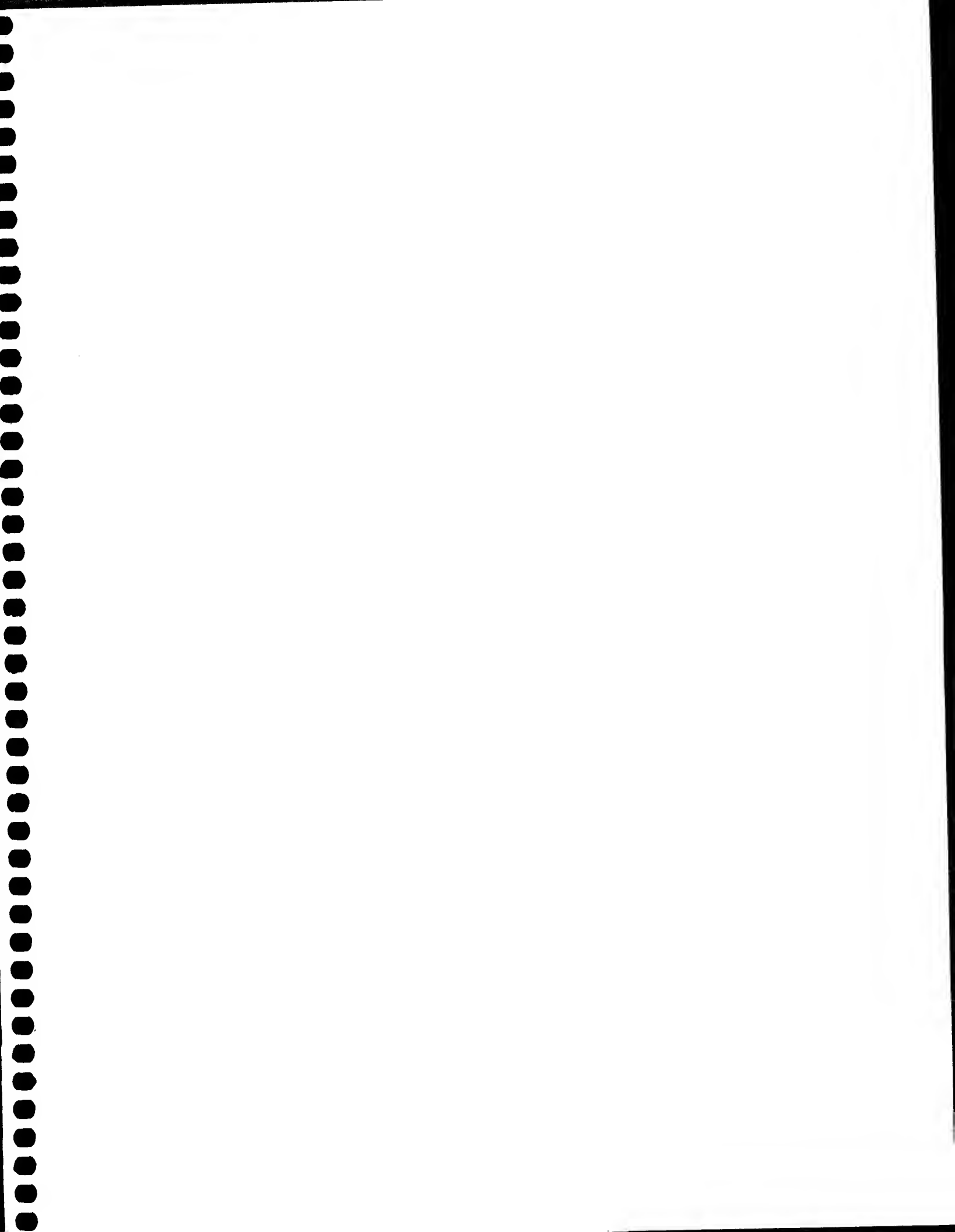
JRL Project No.	Service Nomenclature	Brief Descriptive Title	NRC CRASH		SERVICE PROCUREMENT			
			(1) Del- iver- ies	Cost	Del- iver- ies	Cost	Total Orders	Value
				\$	lbs	\$	lbs	\$
0-500	RR-6/U	Paper Backed Bent Chaff 2700-3400 Mc			626,500	633,000		
0-500	CHA-25	Embossed Bent Chaff 320-600 Mc			1,054,000	158,000		
0-500	CHA-28	Paper Backed Bent Chaff 450-600 Mc			461,600	661,200		
0-500	CHA-28 RR-4/U	Embossed Bent Chaff 450-600 Mc			5,430,000	8,386,500	10,886,500	
0-500	RR-4/U-T	Embossed Bent Chaff- Taped 450-600 Mc			3,620,000	5,416,200	6,240,000	
0-500	CHB-0	Paper Backed Flat Chaff 110-116 Mc			564,000	601,900		
0-500	CHB-1 RR-9/U	Paper Backed Flat Chaff 193-224 Mc			167,000	161,800		
0-1200	CHB-1 RR-2/U	Untuned Rope			2,460,000	4,815,000	3,678,000	
0-1200	CHB-2 RR-3/U	Untuned Rope			2,914,000	4,507,000	3,851,000	
0-1200	RR-3/U-T	Untuned Rope Taped			3,117,000	4,852,000	8,117,000	
0-1110	0-1	Taping Machine			20	70,000		
		Totals	161	96,000	24,942,465	39,473,600	32,772,500	

*Based on Transition Department Final Report - 12-1-45

(1) This column indicates the number of units provided for the Services with transfer of funds from Services to NRC.

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